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The effect of various binders and moisture content on the apparent thermal conductivity of green foundry sand

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THE EFFECT OF VARIOUS BINDERS AND MOISTURE CONTENT ON THE APPARENT THERMAL CONDUCTIVITY OF GREEN FOUNDRY SAND

BY

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A

THESIS

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INTRODUCTION

The broad field of heat transfer is well developed in its theory and mathematics, however, some few applications of varying heat transfer rates have been explored only recently.

Previous to the nineteen-thirties, foundrymen had apparently been interested in heat transfer measurements only from the standpoint of the melting of metals and the heat treatment of the finished castings, with the rate of solidification and the transfer of heat from the casting through the mold being ignored, or at least accepted as an uncontrollable factor. This does not apply, of course, to the use of metal chills to adjust solidification rates of isolated areas of castings.

Perhaps the earliest intensive research on the subject of heat transfer in foundry sands under actual mold conditions was performed by Tanasawa in 1935 [1], whose

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(1) Tanasawa, Y., Trans. Soc. Mech. Engrs., Japan. (English abstract on page S-68) 1935.

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work is referred to by Jacob. [2]

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(2) Jacob, Max, Heat Transfer, Vol. I. N.Y., Wiley, 1949. pp. 320-321.

It is the intent of this thesis to investigate two of the many factors which affect the rate of heat transfer in the damp foundry mold. These two factors are 1) the moisture content of the molding sand, and 2) the type of binder used to serve as a bonding agent between sand grains. The variation of the first factor is restricted to the useable range for each sand mixture tested, which was determined by preliminary moisture, permeability, and green compressive strength tests on the mixtures. The variation of the second factor is limited to only three sand samples, containing, either singly or in combination, only two types of clay binder.

It is the author's hope, that in addition to the technical information gained, this thesis may also serve to further promote the foundry program at the School of Mines and Metallurgy of the University of Missouri and serve to encourage more research at the school directly related to the foundry field.

The conclusions of this thesis, though perhaps lacking in absolute values for heat transfer rates, should serve as a good comparative guide to the properties that may be expected in similar or closely related sand mixes.

REVIEW OF LITERATURE

The most outstanding problem involved in working with heat effects in green foundry sand is the problem of dealing with the migration of the moisture from warmer to cooler areas, or, more particularly, with the migration of the heat of vaporization of the moisture. Tanasawa [3] attempted to evade this difficulty by applying a sinusoidal periodic heat source to the end of a cylindrical sand specimen, using very high frequencies and small amplitudes to minimize the shifting of the moisture. This proved effective, but if the moisture migration can be taken into account, conditions much closer to actual mold conditions can be reached. In addition, this method eliminates the possibility of investigations at or near the pouring temperatures of the metals being cast.

(3) Tanasawa, Y. op. cit., p S-68

Paschkis, in his research sponsored by the Heat Transfer Committee of the American Foundrymen's Society, has made the most recent advances in the field through quite exhaustive investigation with the Heat and Mass Flow Analyzer at Columbia University. [4] Through the use of the electrical analogy, he was able to consider-

(4) Paschkis, V., Heat Flow in Moist Sand, Trans. Amer. Foundrymen's Society. Vol 59. pp. 381-391. 1951.

ably simplify the experimental technique, however, he was limited as to the variables that he was able to take into account.

Paschkis' preliminary tests were concentrated at a pouring temperature of 2600 ^{o}F, but as he has stated in his paper, though this is near the range of the pouring temperatures of steel, the data as applied to moist sand is much more useful to the gray iron and non-ferrous foundrymen, since predominantly dry or very low moisture is used in steel casting sands.[5] In addition, he has

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(5) Ibid.

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shown that the moisture content of the green sand exerts a stronger chilling action at lower temperatures by comparison of temperature distributions through dry and green sand molds at various pouring temperatures. All green sand mixes were taken at a moisture content of 6%.

In further work, Paschkis broadened his study to include a variation in moisture content of the sands.[6].

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(6) Paschkis, V., Heat Flow in Moist Sand. American Foundrymen's Society Annual Meeting Preprint. 1952.

These experiments served to prove that the effects of moisture content on the apparent thermal conductivity of foundry sand had a considerable influence in light castings where the immediate chill removes a large part of the heat of fusion, but has lesser influence in heavier castings where the immediate chill produced by the damp sand does little toward the solidification of the casting. Even in heavier castings, however, if a surface chilling results in the forming of a different surface structure in the casting, the moisture content will have a varying and important effect.

In the field of centrifugal casting in steel molds, Register, Taylor, and Rightmire investigated the surface coefficient of heat transfer for the metal-mold interface. [7] They found that an insulating wash of clay on

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(7) Register, C. L., Taylor, H. F., and Rightmire, B.G. Heat Transfer Coefficients of Centrifugal Casting. American Foundryman. Vol. 20, No. 5, pp. 34-37. (1951)

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the mold face made no apparent change in this surface coefficient. It may be expected, then, that a change in moisture content of the green sand mold will affect the apparent thermal conductivity of the mold only from the standpoints of heat transferred within the sand mold by convection, conduction, and radiation. The only surface condition that could be expected to change the surface coefficient would be a change in surface texture, that is, in the case of a sand mold, a change in grain size or distribution of the sand. The degree of ramming is considered constant.

DISCUSSION

Most experimental procedures for obtaining the temperature distribution in either castings or in sand molds make use of a near-infinite cast slab of a finite thickness. Since molding and melting capacities were somewhat limited, it was decided here to form the test mold in the shape of a hollow cylinder with insulated ends so that the cylinder may be treated as one of infinite length. Casting a solid cylinder of metal in a cylindrical mold corresponds to the situation investigated by Perry and Berggren [8], who worked a graphical

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(8) Perry, R. L., and Berggren, W. P. Transient Heat Conduction in Hollow Cylinders After Sudden Change of Inner Surface Temperature. Univ. of California Publications in Engr. Vol. 5, No. 3, pp. 59-88. 1944

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solution of radial heat conduction in a solid cylinder with a sudden rise of inside surface temperature from the temperature of the entire cylinder to some constant higher temperature, as long as two main conditions are met:

1) The metal is poured into the mold very quickly so that the sudden or instantaneous rise of inner surface temperature may be assumed.

2) The accuracy of the values of apparent thermal conductivity obtained are limited by the time of solidification of the metal being cast.

The first condition may be satisfied by the use of baked sand cores to make up the sprue and gate leading into the mold cavity. These will allow very fast pouring of the molten metal by minimizing the amount of washing through the errosion resistance of the baked sand cores.

The second condition stated certainly proves to be no problem from the investigator's standpoint, but should serve as a limitation on the application of the obtained values. However, if only comparison of the thermal properties of various molding sand mixes is desired, it imposes no limits.

Construction of Pattern Equipment

A cylindrical flask, 11 inches in diameter and 10 1/2 inches high was constructed as shown in Figure 1. The 3/8 inch holes drilled on 1 1/2 inch centers served both as ports for the escape of the mold gases and as entrances for the thermocouple housings.

A wood matchplate for molding a 2 inch cylinder 9 inches long was fabricated, including the core print for a baked sand core to form the gating system. For ease of molding, a one degree draft was allowed on the cylinder pattern, the 2 inch diameter dimension being held at the plane on which the sand temperature readings were taken. The matchplate is shown in Figure 2.

The first core box in Figure 3 was made to form a 2 inch pouring cup which made up the entire sprue for the mold. The second core box shown in Figure 3 formed the core for the single-gate gating system for the casting. The forms of the cores themselves are shown on the right hand side of the figure.

Since it was necessary to have some facility for minimizing the heat losses at the top and bottom of the mold, 1/2 inch celotex insulating board was cut into discs and used for this purpose. The top board was applied before the sand was placed on the matchplate and the bottom insulating board was applied after the leveling off of the jolted sand and before the bottom board was seated. A 1/4 inch thick transite disc was formed to serve

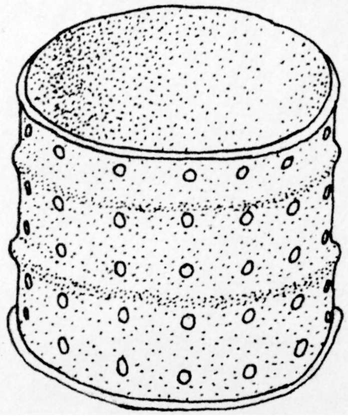


FIG. ① CYLINDRICAL, ONE PIECE FLASK FOR TEST MOLDS.

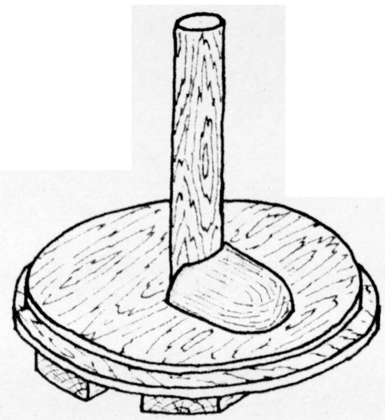


FIG. ② MATCHPLATE FOR TEST MOLD

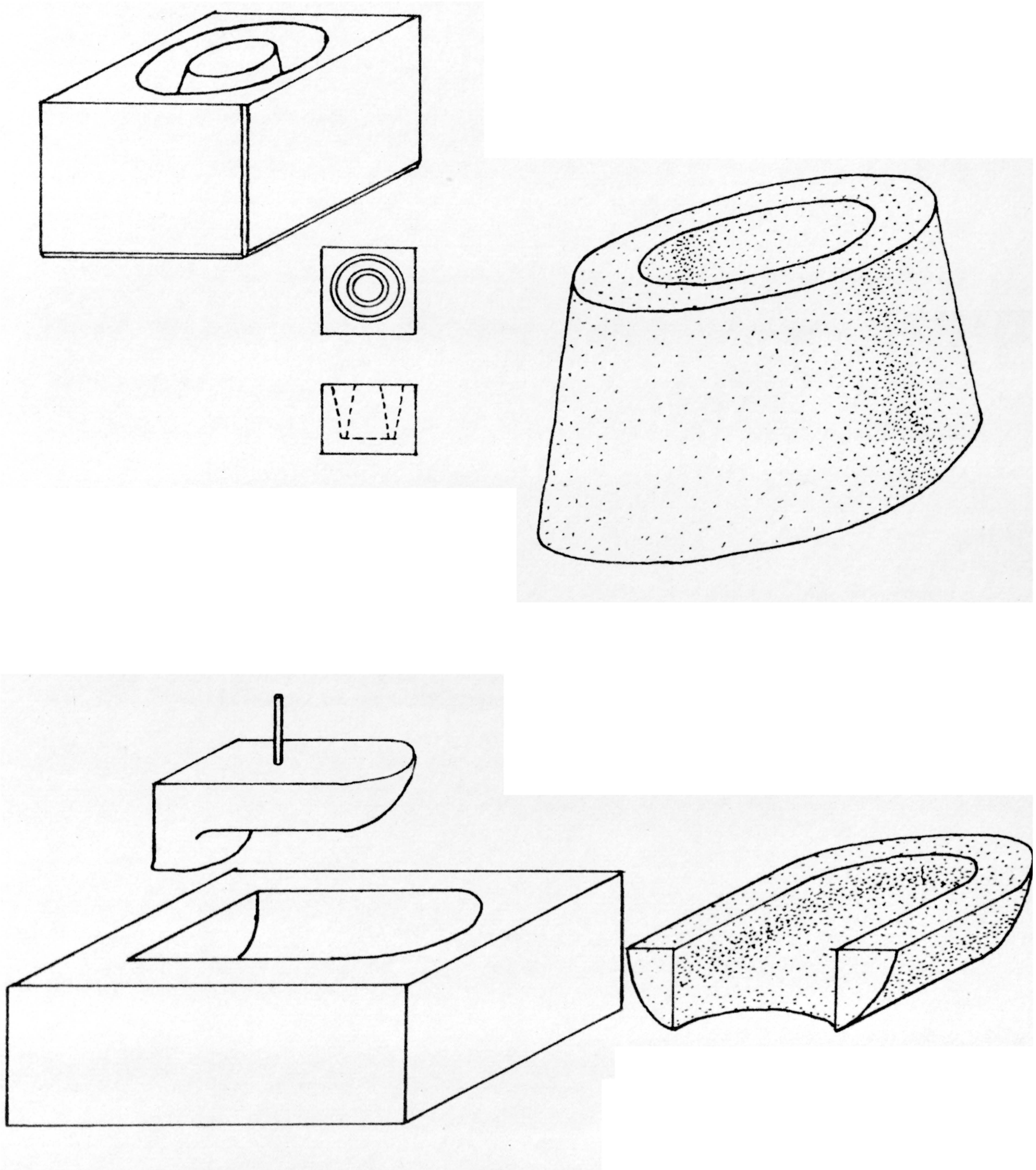


FIG. ③ CORES AND CORE BOX EQUIPMENT FOR TEST MOLDS both as a cover for the gate core and as a solid base for the pouring cup core to rest upon.

Thermocouple Equipment

Six Chromel-Alumel thermocouples were made in 3/8 inch porcelain insulating tubes. The tubes themselves were approximately 6 inches long, and the thermocouple wires were carried 1 1/2 inches beyond the ends for the cold junctions. The hot junction ends were twisted and welded close to the end of the porcelain tube. Precautions were taken to keep the cold junctions at a reasonably constant temperature. During calibration, they were shielded from the radiation of the solidifying metal samples, and due to the comparatively short runs during experimentation, the remained fairly close to room temperature. (75°F)

These six thermocouples were connected to the switching and measuring devices as shown in Figure 4 by insulated copper lead wires.

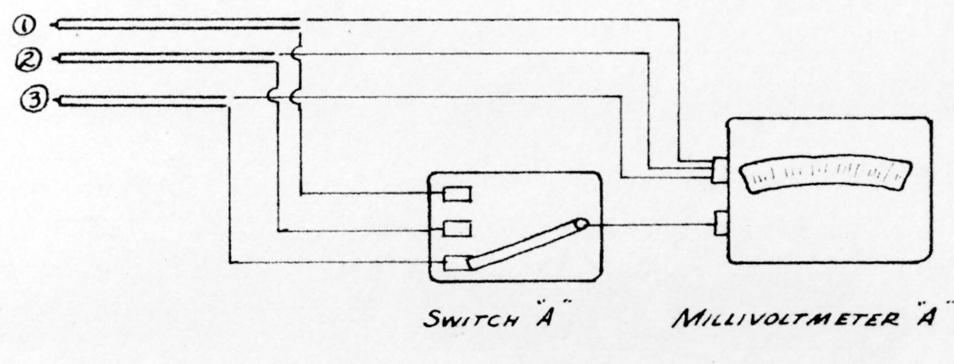
The heavy copper switches for the thermocouple circuits were constructed by the author because no similar switches were immediately available.

Calibration was carried out by determination of fixed points, the following points being used:

Boiling point of water

Melting point of Tin

Melting point of Zinc



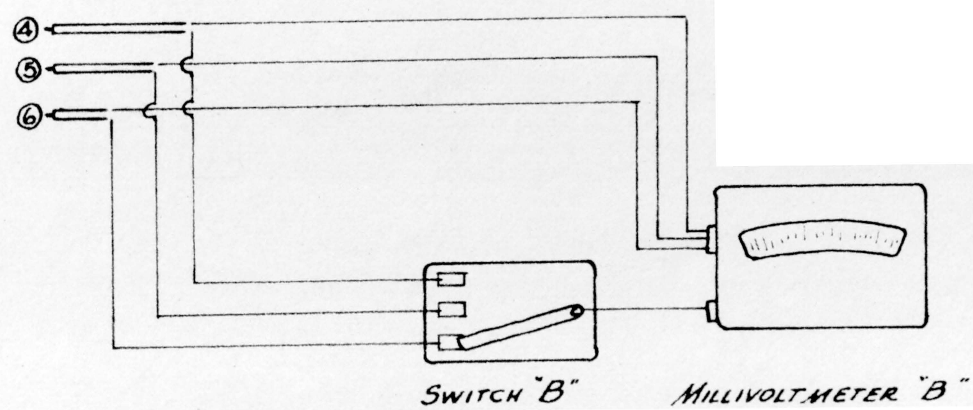


Fig. ④ Arrangement of Thermocouple Circuits

Melting point of Aluminum

The results of this calibration work are shown in Table 1 and are plotted in Figure 5.

The instrument referred to in Figures 4 and 5 as Millivoltmeter "A" had the following identification:

Hoskins Thermoelectric Pyrometer

0-44 Millivolts   Type HA No. 0

Serial No. 14852

Ext. Res. (meter)   1 ohm

Int. Res. (meter)   250 ohms

The instrument referred to in Figures 4 and 5 as Millivoltmeter "B" had the following identification:

Wilson-Maeulen Co., N.Y.

0-20 Millivolts   Form T. No. TY 47

Ext. Res.   100 ohms

Table 1

Calibration of Thermocouples

Group "A"

Couple No.	1	2	3
Calibration Point	Reading in Millivolts		
Tin M.P.	8.65	8.60	8.50
Zinc M.P.	16.4	16.5	16.5
Al M.P.	25.4	25.2	25.0
Water B.P.	3.0	3.0	3.0

Group "B"

Couple No.	4	5	6
Calibration Point	Reading in Millivolts		
Tin M.P.	4.10	4.05	3.8
Zinc M.P.	7.85	7.85	7.6
Al M.P.	12.05	11.82	11.70
Water BP.	1.27	1.25	1.20

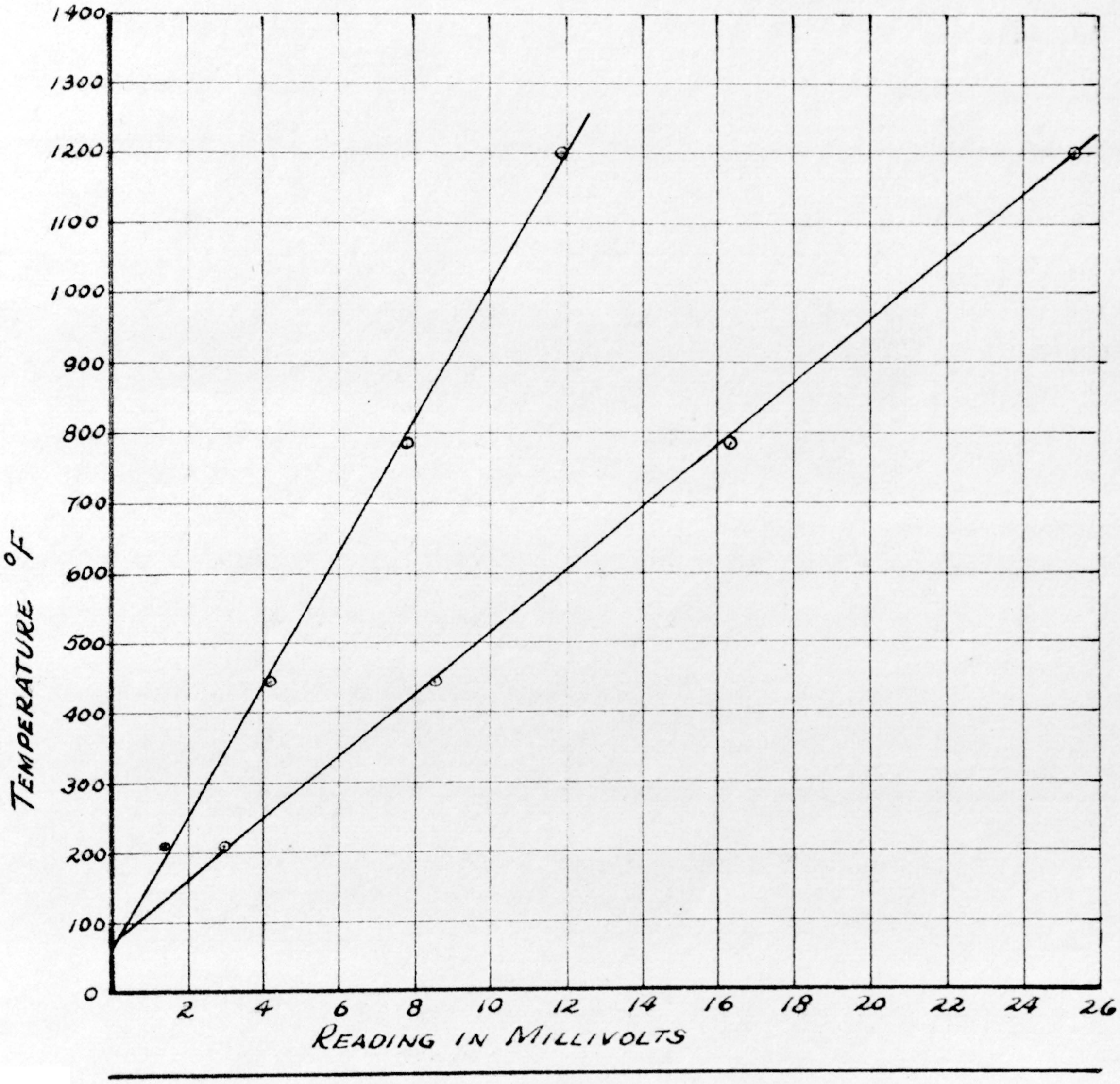


FIG. 5 THERMOCOUPLE CALIBRATION CURVES.

Mixing of Sand Samples

Ottawa Number 60 silica sand was used in the three synthetic mixes tested. Several mixes were made in small quantities and the following three were chosen for the tests on the basis of arbitrary workability, moldability, and ease of comparison.

Sample No. 1

93 % Silica Sand

7 % Southern Bentonite

Sample No. 2

93% Silica sand

3 1/2 % Southern Bentonite

3 1/2 % Western Bentonite

Sample No. 3

93 % Silica sand

7 % Western Bentonite

Preliminary Sand Testing

Three screen analyses were made on the original Ottawa Number 60 silica sand, and the A.F.S. Fineness Number was calculated to include the 7 % clay addition, which was made later. The standard A.F.S. screen series was used, with U.S. Series Equivalent Numbers of 6, 12, 20, 30, 40, 50, 70, 100, 140, 200, 270, and pan.

The weights shown in Table 2 are averages for the three runs.

The size and distribution of sand grains is represented graphically by the curve in Figure 6, which has cumulative percentage retained as ordinate and log of the grain size as abscissa.

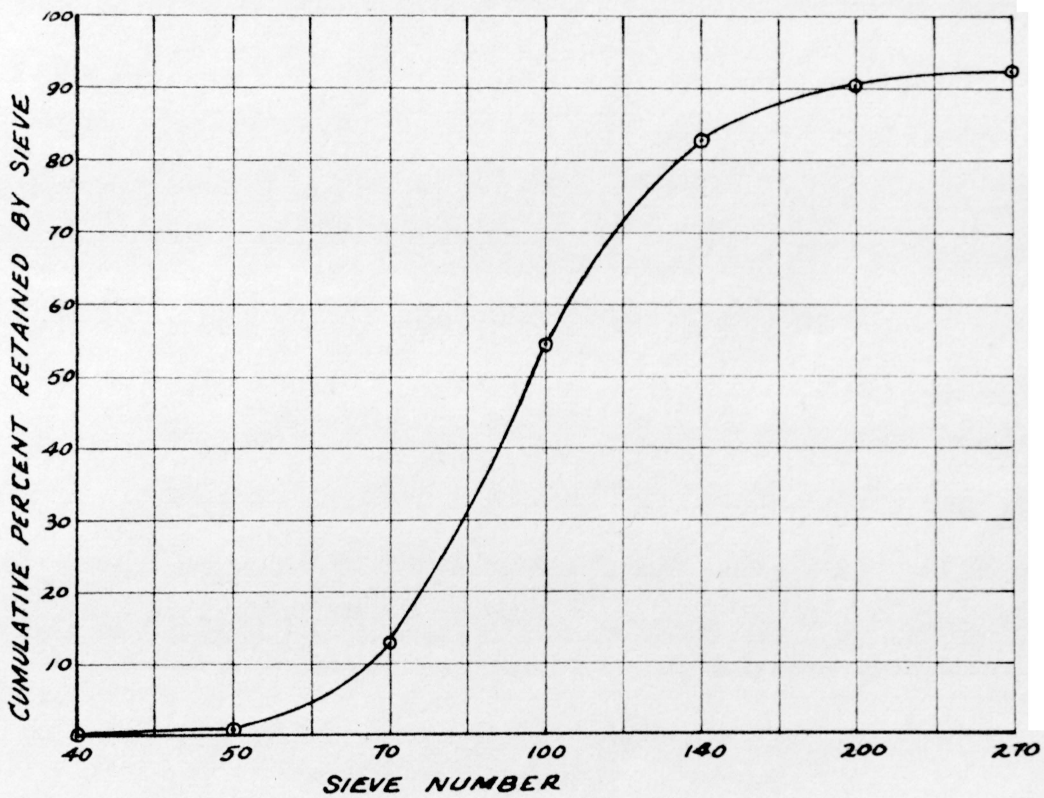
Table 2

Grain Size Distribution and Fineness Number

#60 Ottawa Silica Sand

Sieve No.	Grams Retained	% Retained	Mult. Factor	——	Cum. % Retained
6 - 40	0.00	--	--	--	0.0
50	0.06	0.113	40	4.52	0.113
70	6.77	12.7	50	635.0	12.813
100	22.31	41.9	70	2933.0	54.713
140	14.90	28.0	100	2800.0	82.713
200	4.19	7.87	140	1101.8	90.583
270	0.845	1.59	200	318.0	92.173
Pan	0.360	0.677	300	203.10	92.850
		92.850		7995.42	

$$\text{Fineness Number} = \frac{7995.42}{92.850} = \underline{\underline{86.11}}$$



DATA OBTAINED FROM REPRESENTATIVE SAMPLES OF THE SAND USED FOR ALL MOLDING SAND MIXES.

FIG. 6 GRAPH OF SAND GRAIN DISTRIBUTION

The greater portion of the preliminary sand testing consisted of investigation of the moisture-permeability and moisture-green compressive strength relations for the three sand samples. This was done in order to determine the useable moisture range for each of the mixes so that the thermal tests could be performed at moisture contents within these ranges.

Small, hand-mixed batches were used for the preliminary tests. The test procedure was as follows.

A representative 5 pound sample of the silica sand was taken, the clay added, and the two thoroughly mixed by hand. Moisture was added in small steps, varying from 0.5 % to 1.0 %. After each water addition, the batch was hand-mixed until uniform and put through a # 10 hand riddle.

Standard 2 inch cylindrical sand specimens were prepared and tested for permeability on a Dietert Permeability Meter and for green compressive strength on a Dietert Universal Strength Testing Machine. At the same time, moisture tests were performed on a Dietert Moisture Teller It is to be noted that the moisture percentages are based on the weight of the green sand, that is,

$$\text{Percent Moisture} = \frac{\text{Weight lost in drying}}{\text{Weight of damp sand}}$$

This data for each of the three samples is shown in Tables 3, 4, and 5. Graphs of permeability vs. moisture and green compressive strength vs. moisture are plotted for the three samples in Figures 7 through 12.

Dry compressive strength tests were also made on the three sand mixes. The sand was prepared in the same manner as for the green tests, formed into standard 2 inch cylindrical specimens, dried for one hour at 200 °F, and tested on the Universal Strength Testing Machine. The results of these tests are also included in Tables 3, 4, and 5.

From the graphs of green properties against moisture content, the following moisture contents were chosen as the most desireable percentages to be used for green molds of the three mixes:

Sample No. 1	2.75 % Moisture
Sample No. 2	2.5 % Moisture
Sample No. 3	3.0 % Moisture

These desireable moisture contents were chosen as the points for concentrated comparison of the effects that the type of binder has on the thermal properties.

In addition, it was decided that the thermal tests be applied to the following useable ranges for the three mixes:

Sample No. 1	2.0-4.0 % Moisture
Sample No. 2	1.5-3.5 % Moisture
Sample No. 3	2.0-4.0 % Moisture

Table 3

Green Testing Results

Sand Sample No. 1

7% Southern Bentonite

Percent Moisture	Perm. No.	Green Comp. Strength p.s.i.	Green Comp. Strength p.s.i.	Green Comp. Strength p.s.i.
1.8	45	14.5	13.5	13.8
2.6	50	14.1	15.7	14.8
2.8	57	14.4	15.1	14.8
3.2	54	11.8	10.6	10.9
3.7	55	10.05	11.4	10.5
3.95	53	8.85	8.6	8.7
4.3	49	7.9	8.05	7.8
4.8	41	7.15	7.5	7.8
5.3	42	6.8	6.7	6.7

Dry Comp. Strength 17.0 p.s.i.

17.2

17.0

Table 4

Green Testing Results

Sand Sample No. 2

3 1/2 % Southern Bentonite

3 1/2 % Western Bentonite

Percent Moisture	Perm No.	Green Comp. Strength p.s.i.	Green Comp. Strength p.s.i.	Green Comp. Strength p.s.i.
1.6	49	9.1	8.9	9.7
2.2	51	11.25	12.35	11.5
2.4	54	11.0	11.3	11.3
3.0	54	9.7	11.6	10.5
3.3	53	9.45	8.65	8.9
3.8	50	7.8	8.5	7.9
4.2	48	6.5	8.3	6.9
5.1	45	6.2	6.2	6.2

Dry Comp. Strength 43.0 p.s.i.

38.5

42.5

Table 5

Green Testing Results

Sand Sample No. 3

7% Western Bentonite

Percent Moisture	Perm. No.	Green Comp. Strength p.s.i.	Green Comp. Strength p.s.i.	Green Comp. Strength p.s.i.
2.1	49	11.6	11.35	11.4
2.7	50	12.1	12.1	11.7
3.2	51	10.8	11.8	11.3
3.4	52	9.65	10.9	11.5
3.6	50	8.5	8.65	9.05
4.2	49	7.35	8.1	8.6
4.6	45	7.3	7.2	7.7

Dry Comp. Strength over 93.5 p.s.i.

over 93.5

over 93.5

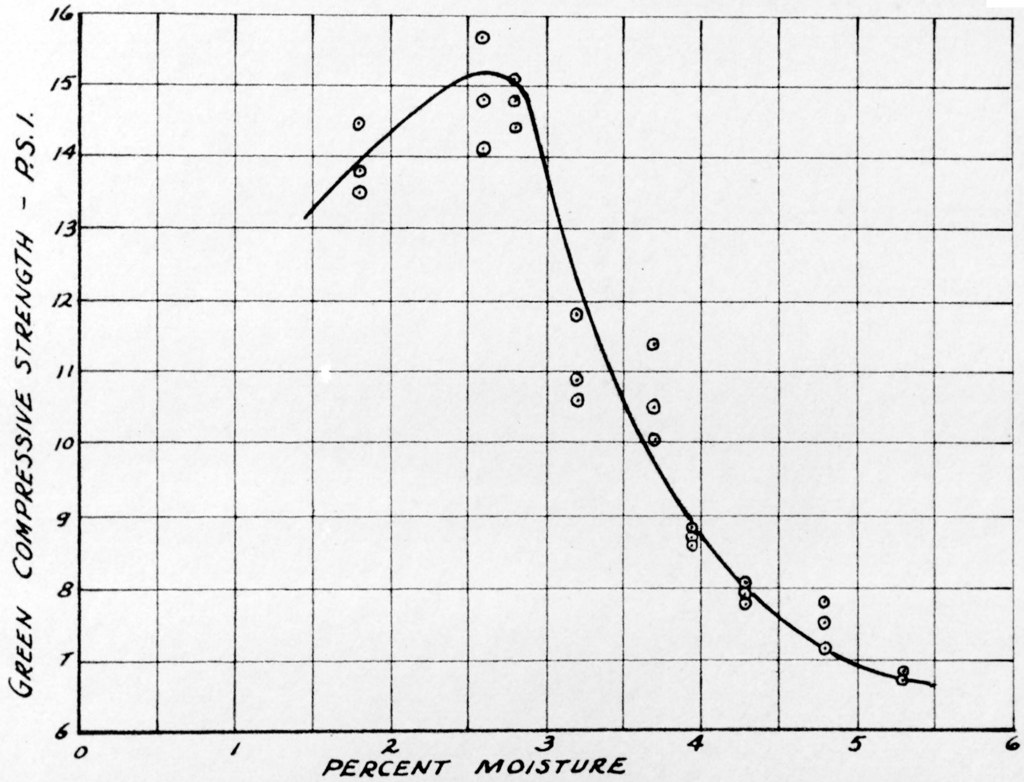


FIG. 7 STRENGTH-MOISTURE RELATIONSHIP, MIX NO. 1

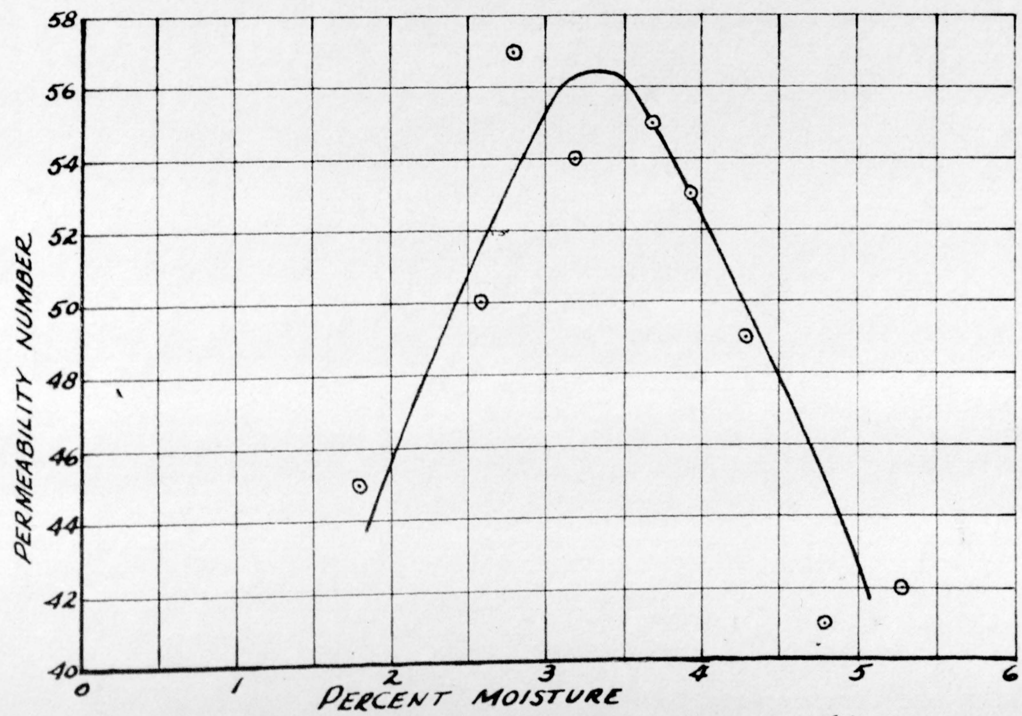


FIG. 8 PERMEABILITY-MOISTURE RELATIONSHIP, MIX NO. 1

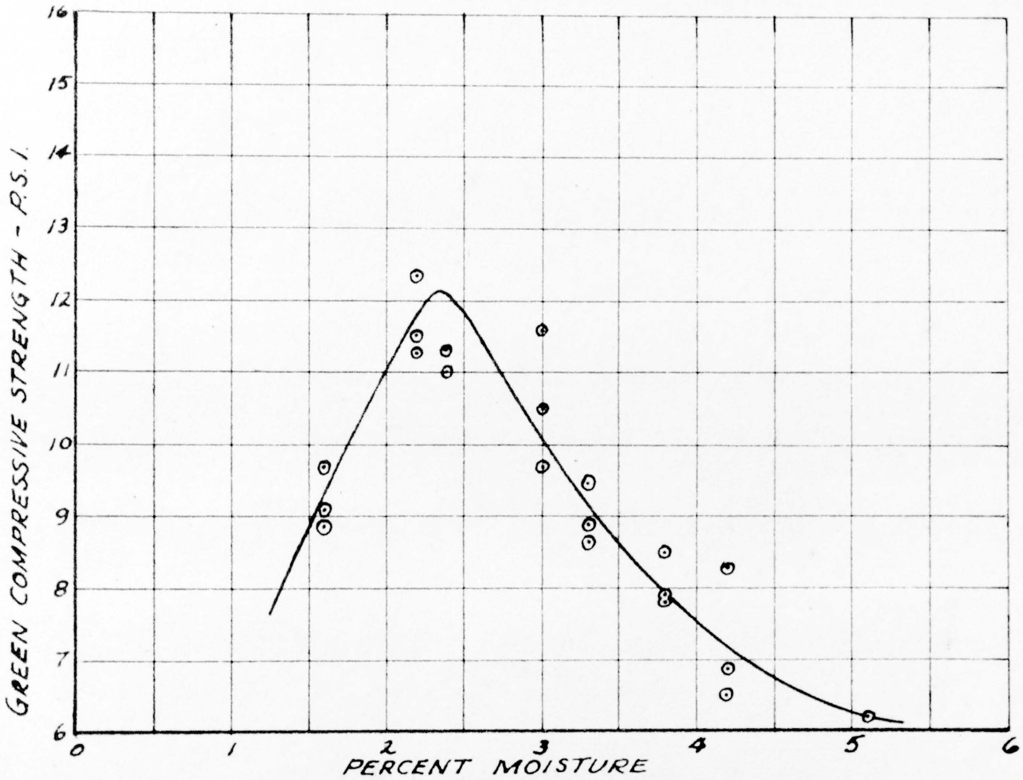


FIG. 9 STRENGTH-MOISTURE RELATIONSHIP, MIX NO. 2

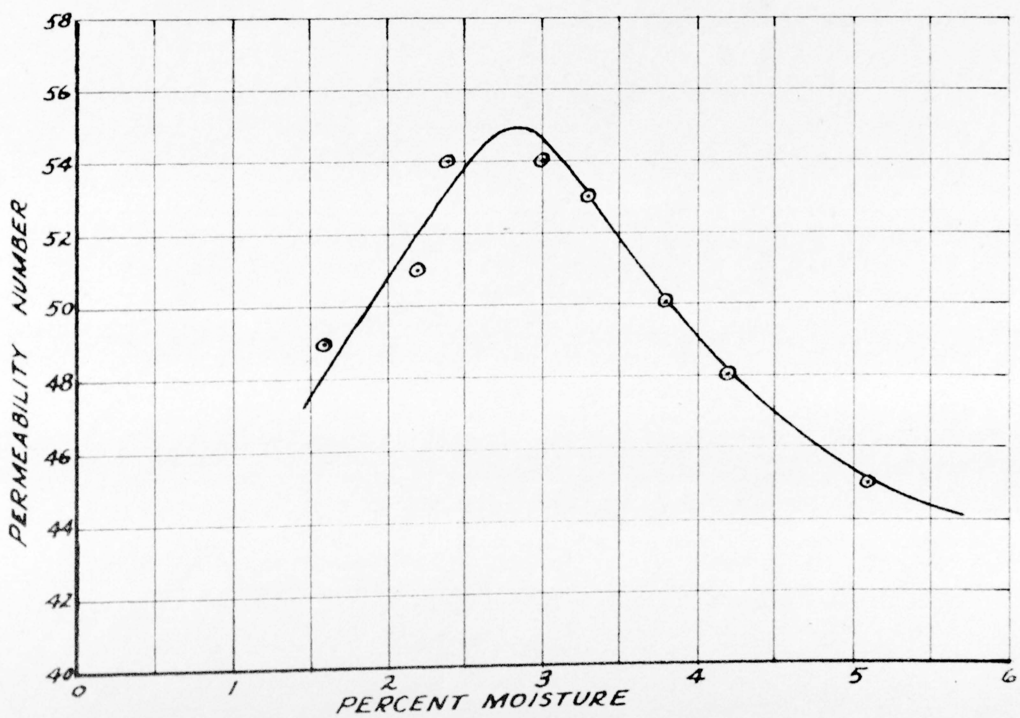


FIG. 10 PERMEABILITY-MOISTURE RELATIONSHIP, MIX NO. 2

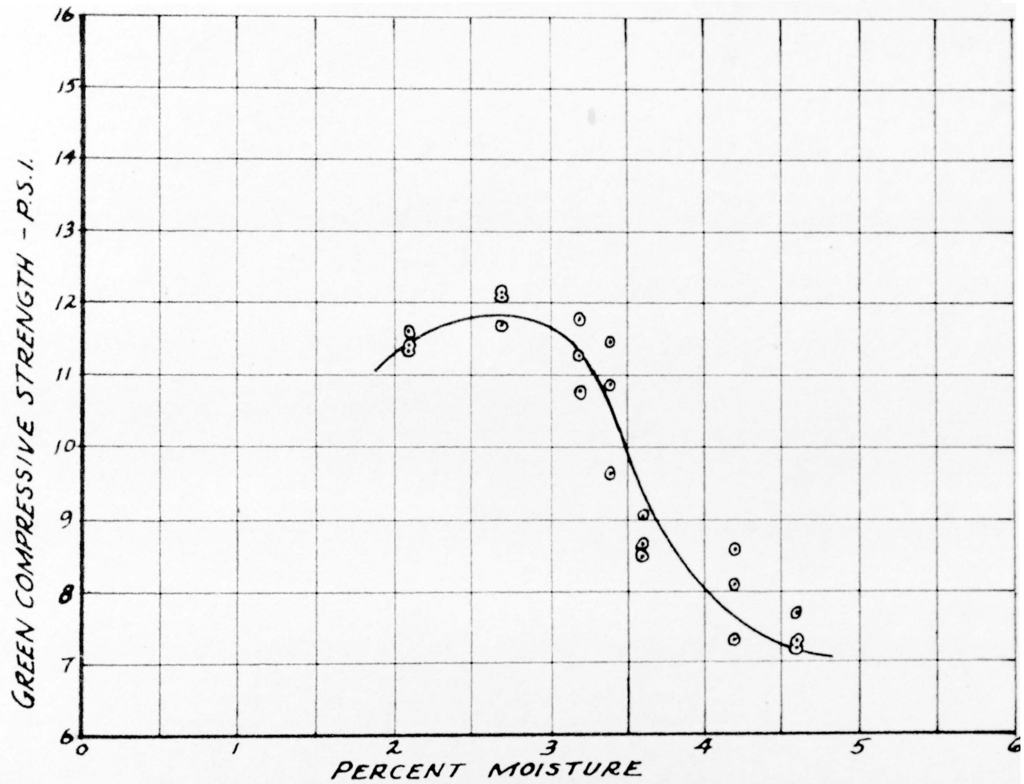


FIG. 11 STRENGTH-MOISTURE RELATIONSHIP, MIX NO. 3

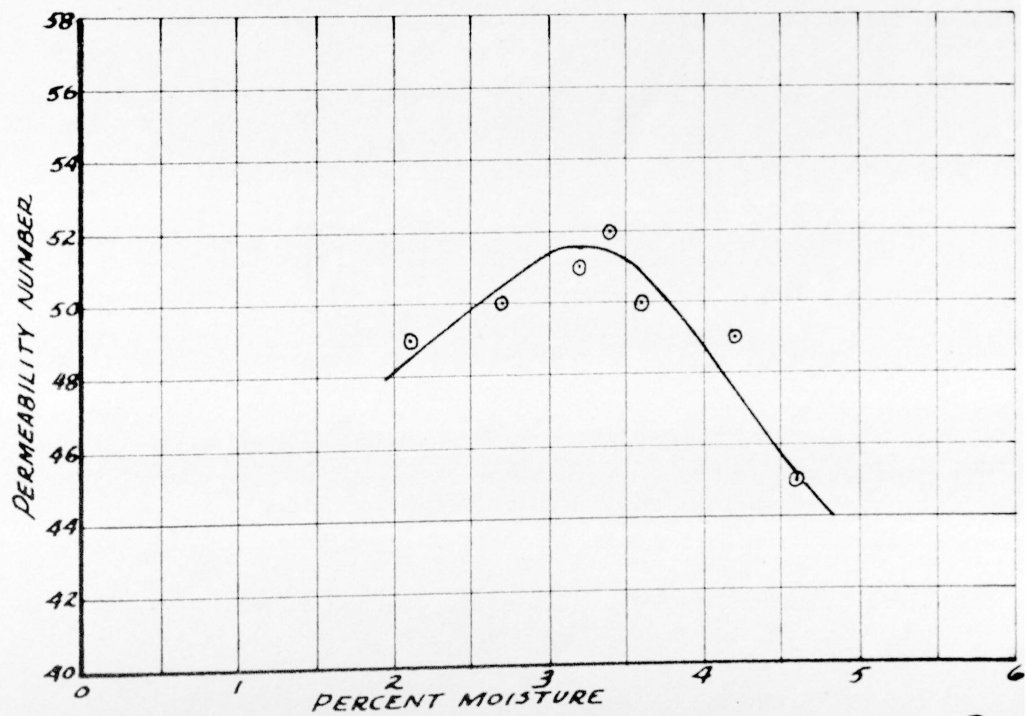


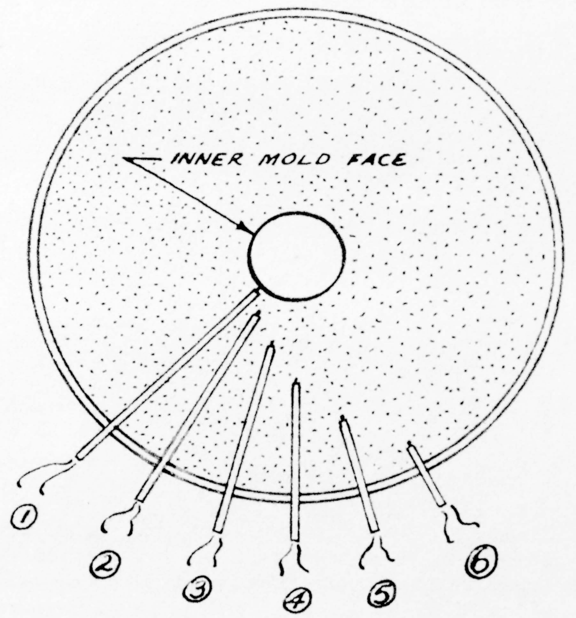
FIG. 12 PERMEABILITY-MOISTURE RELATIONSHIP, MIX NO. 3

Molding Procedure

Mixing of sand samples for the thermal tests was done in a muller. 100 pounds of silica sand was placed in the muller, the proper amount of binder added, and the dry ingredients mixed for one minute. Water was then added to give the desired moisture content and the entire batch mulled for 8 minutes.

Upon removal from the muller, the sand was run through a Royer for aeration and the breaking down of lumps. This step eliminated hand riddling at the mold.

On the molding machine, the top celotex insulating circle was placed on the matchplate, the flask placed over it, and the flask filled with sand. The flask was filled to heaping and the flask was jolted approximately 30 times. The excess sand was struck off to 3/8 inches below the flask edge and the bottom insulating board and the bottom board were applied. The mold was then squeezed to compact the extra 1/8 inch of sand and seat the bottom board against the flask. The mold was then rolled over. Before the removal of the matchplate, a vent wire was used to form the radial holes for the placement of the thermocouples as shown in Figure 13. These holes were made slightly short of the final position of the hot junction of the thermocouples to assure good thermal contact between the thermocouples and the sand when the thermocouples were inserted to full depth.



THERMOCOUPLE NUMBER	DISTANCE FROM INNER MOLD FACE
1	0 INCHES
2	3/8 INCHES
3	7/8 INCHES
4	1 1/2 INCHES
5	2 3/8 INCHES
6	3 1/2 INCHES

FIG. 13 PLACEMENT OF THERMOCOUPLES IN TEST MOLD.

The matchplate was then removed, the gate core placed, the transite cover positioned, and the pouring cup core set. The mold was then removed to the pouring area and the thermocouples placed in the holes.

The entire mold assembly is shown in Figure 14.

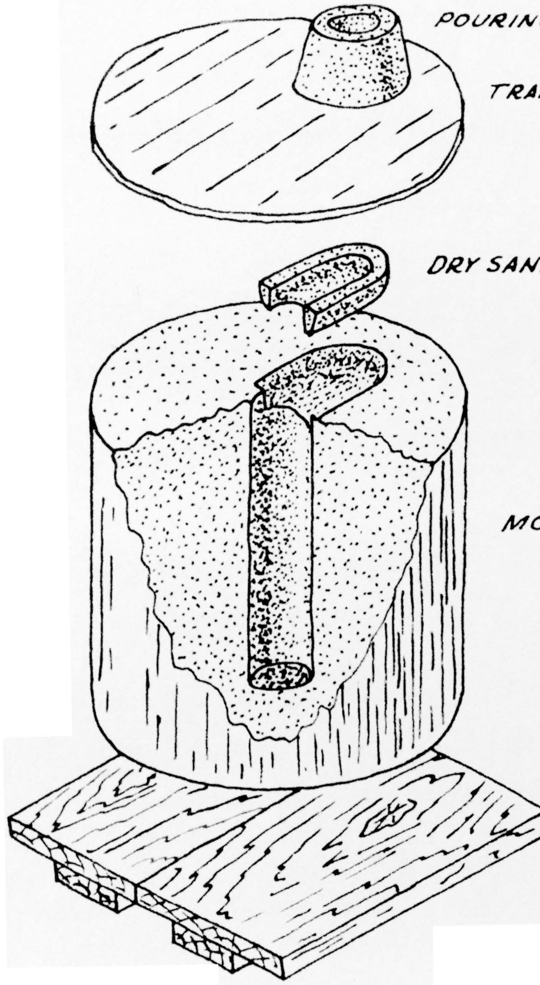


FIG. 14 EXPLODED CUTAWAY VIEW OF TEST MOLD

Thermal Tests

An effort was made in the running of the tests to pour the aluminum at a fairly constant temperature and to have this temperature as near the melting point as possible. An immersion pyrometer was used for the temperature determination immediately before pouring. The melting point of the aluminum alloy used in the testing was apparently 1045 °F, and it was found to be necessary that the test molds be poured at slightly over 1100 °F to prevent freezing of the metal on the sides of the crucible.

The metal was poured as quickly as possible, the timing being started when the mold was approximately half full (full to the level of the plane of the thermocouples).

Since no automatic recording devices were used, the thermocouple switches were operated manually and the reading of the millivoltmeters did not take place at definite intervals. The fact that readings were not taken with regularity should cause no error, however, if they could have been taken more frequently, smoother and more definite curves could have been obtained.

Tables No. 6 through 14 show the results of the thermal tests of the nine mixtures. Table No. 10 includes the readings for all six thermocouples, but since the temperature rise was so slight and slowly attained at the positions of Thermocouples 5 and 6, these readings were abandoned through the rest of the experimentation.

From the data in Tables No. 6 through 14, the graphs shown in Figures 15 through 23 were drawn. These graphs of temperature versus time show curves for each of the four thermocouples used.

The first curve on each graph shows the temperatures at the casting face itself. The horizontal portion shows approximately the solidification period. Representing the temperature of the casting surface, the first curve may also be considered to represent the temperature of the sand at the inside surface of the mold. This, of course, is not exactly true due mainly to the steam film that is generally considered to separate the two surfaces and act as an insulating layer. Since this insulating effect would be the same for all tests run, it can be ignored in the comparisons of the different mixes.

The general pattern of the other three curves in each figure is as follows: There is a rise in temperature from the original mold temperature (room temperature) to about 210 ^{o}F. The curve is then horizontal (constant temperature) while all of the moisture held by the sand is converted into steam. As soon as this vaporization, or drying, is complete, the temperature again rises.

The change in the general shapes of the two curve sections before and after drying is due mainly to the decrease in the apparent thermal conductivity of the sand when drying occurs.

The length of time necessary for drying increases as the distance from the casting face increases for two reasons: 1) The available heat for vaporization is less as the distance becomes greater. 2) The outer layers contain more moisture to be vaporized than do the inner layers. The second reason may not be readily apparent. It may be reasoned that, as the moisture is vaporized in the inner layers and driven outward, there will be a condensation and deposit of that moisture as it reaches layers of the mold that are below its boiling temperature. It can be seen that there could very well be quite a great moisture buildup in the outer layers.

Table 6

Temperature - Time Data

Sand Sample No. 1

7% Southern Bentonite

2.0% Moisture

Thermocouple readings in millivolts have been converted to °F.

Thermocouple 1 Time sec.	Thermocouple 1 °F	Thermocouple 2 Time sec.	Thermocouple 2 °F	Thermocouple 3 Time sec.	Thermocouple 3 °F	Thermocouple 4 Time sec.	Thermocouple 4 °F
20	1100	30	105	110	110	75	75
80	1100	75	180	225	140	240	80
165	1080	140	210	305	170	415	110
265	1045	170	210	350	200	560	140
370	1045	210	225	435	200	680	170
480	1045	270	240	520	200	770	200
610	1005	385	260	665	200	860	200
730	945	530	270	740	220		
		690	320	825	240		
		815	335				

Fig. 15 Temperature - Time Relationships

Sand Sample No. 1

7% Southern Bentonite

2.0% Moisture

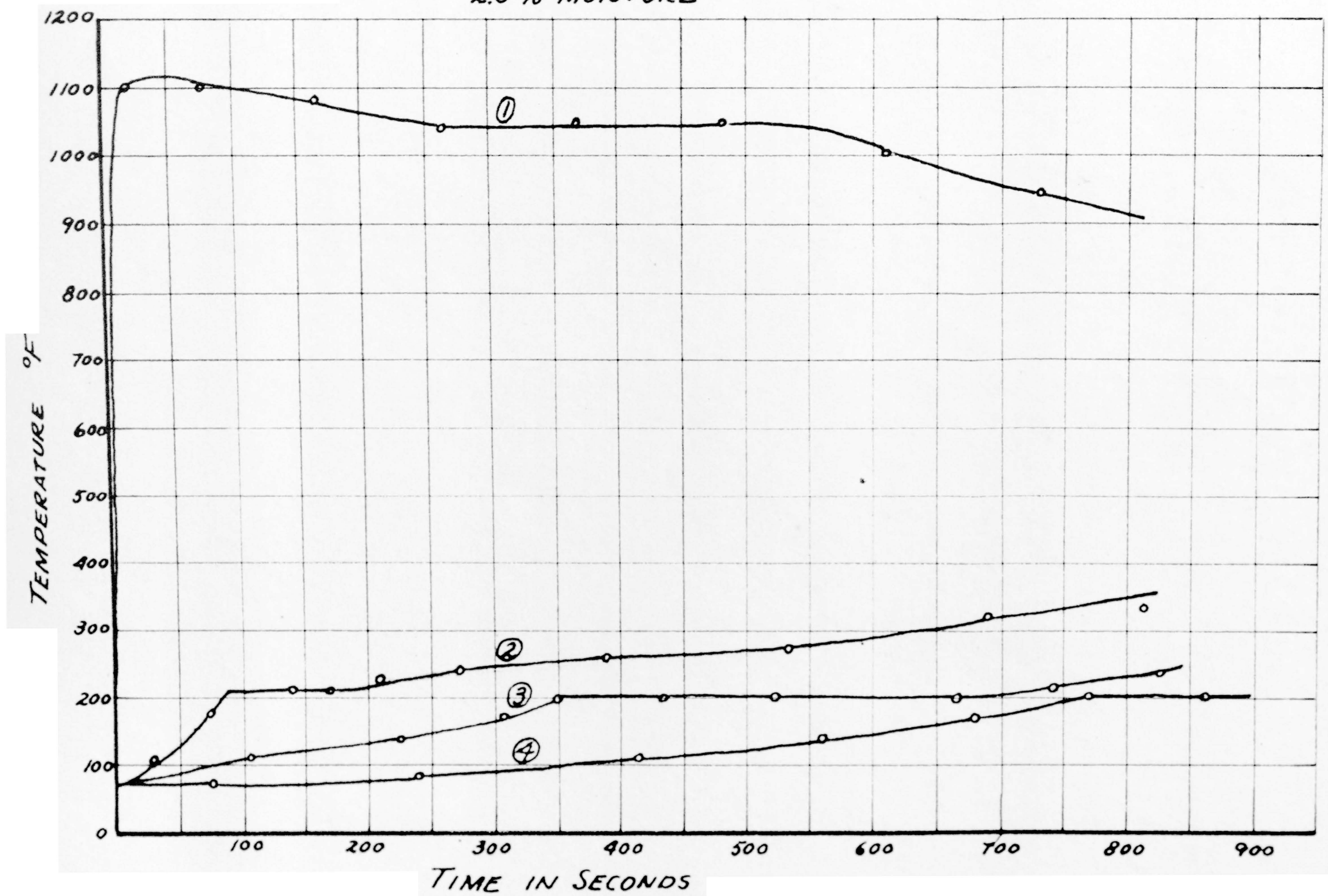


Table 7

Temperature - Time Data

Sand Sample No. 1

7% Southern Bentonite

2.75% Moisture

Thermocouple readings in millivolts have been converted to °F.

Thermocouple 1		Thermocouple 2		Thermocouple 3		Thermocouple 4	
Time sec.	°F	Time sec.	°F	Time sec.	°F	Time sec.	°F
25	1090	35	130	70	105	80	75
60	1105	65	180	110	125	190	90
130	1080	90	210	175	140	265	110
240	1050	145	210	260	160	380	120
340	1045	205	210	315	190	490	140
450	1045	260	225	365	200	625	180
530	1040	350	240	480	200	665	200
670	975	465	250	545	200	735	200
785	925	615	270	640	200		
		720	300	690	200		
		825	325	810	220		

Fig. (16) Temperature-Time Relationships

Sand Sample No. 1

7% Southern Bentonite

2.75% Moisture

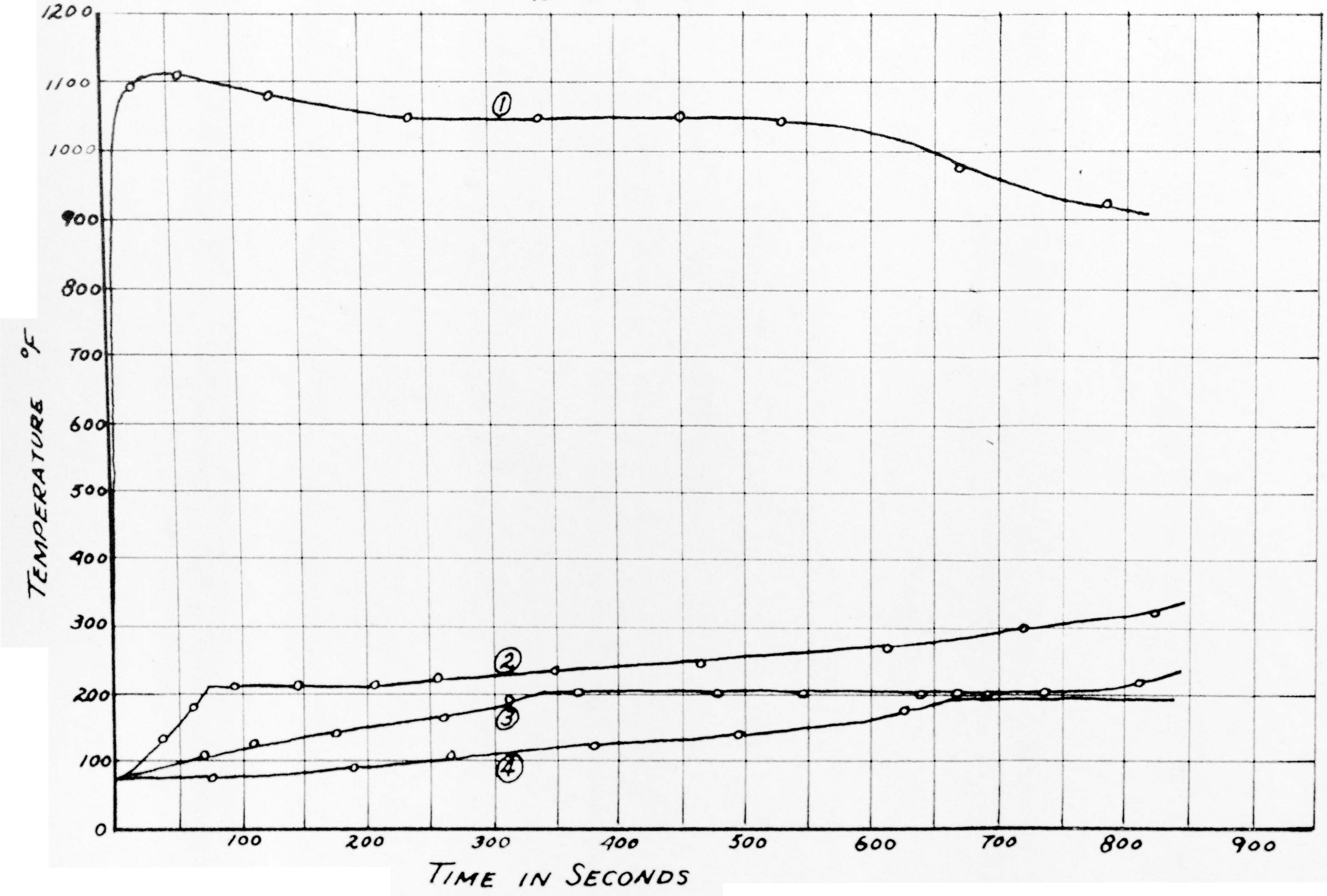


Table 8

Temperature - Time Data

Sand Sample No.1

7% Southern Bentonite

3.50% Moisture

Thermocouple readings in millivolts have been converted to °F.

Thermocouple 1		Thermocouple 2		Thermocouple 3		Thermocouple 4	
Time sec.	°F	Time sec.	°F	Time sec.	°F	Time sec.	°F
20	1080	25	120	60	110	90	80
75	1100	45	180	150	150	170	95
140	1060	70	210	245	180	280	120
220	1040	160	210	320	210	395	140
290	1045	230	210	425	210	530	160
420	1045	310	220	540	210	615	190
510	1045	380	240	665	210	670	210
625	1000	530	250	770	210	760	210
725	940	640	260	850	225		
820	890	745	280				
		835	310				

FIG. 17 TEMPERATURE-TIME RELATIONSHIPS

SAND SAMPLE NO. 1

7% SOUTHERN BENTONITE

3.5 % MOISTURE

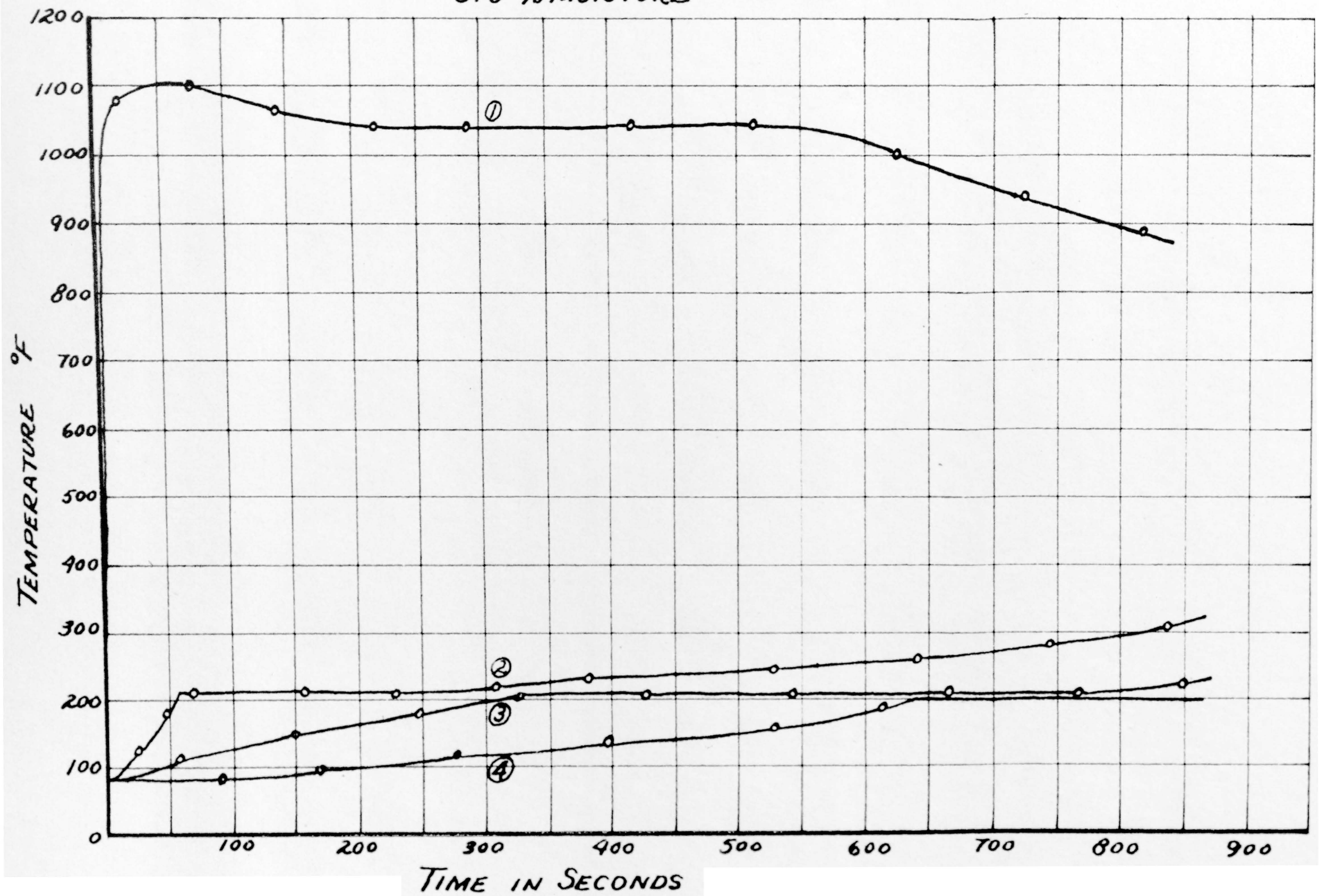


Table 9

Temperature - Time Data

Sand Sample No. 2

3 1/2% Southern Bentonite

3 1/2% Western Bentonite

1.5 % Moisture

Thermocouple readings in millivolts have been converted to ^oF.

Thermocouple 1		Thermocouple 2		Thermocouple 3		Thermocouple 4	
Time sec.	^oF	Time sec.	^oF	Time sec.	^oF	Time sec.	^oF
30	1140	45	100	70	80	115	75
110	1105	80	150	145	90	180	75
190	1080	110	180	210	100	270	75
260	1080	130	210	240	120	400	80
310	1045	170	210	280	125	500	90
380	1045	230	225	350	160	590	100
470	1045	290	240	440	200	720	150
560	1045	330	260	480	200	790	180
630	1025	430	280	520	200	825	210
720	975	495	295	610	200	920	210
830	940	540	300	740	210		
900	920	720	330	870	220		
		920	360				

FIG. 18 TEMPERATURE - TIME RELATIONSHIPS

SAND SAMPLE NO. 2

3½ % SOUTHERN BENTONITE
3½ % WESTERN BENTONITE

1.5 % MOISTURE

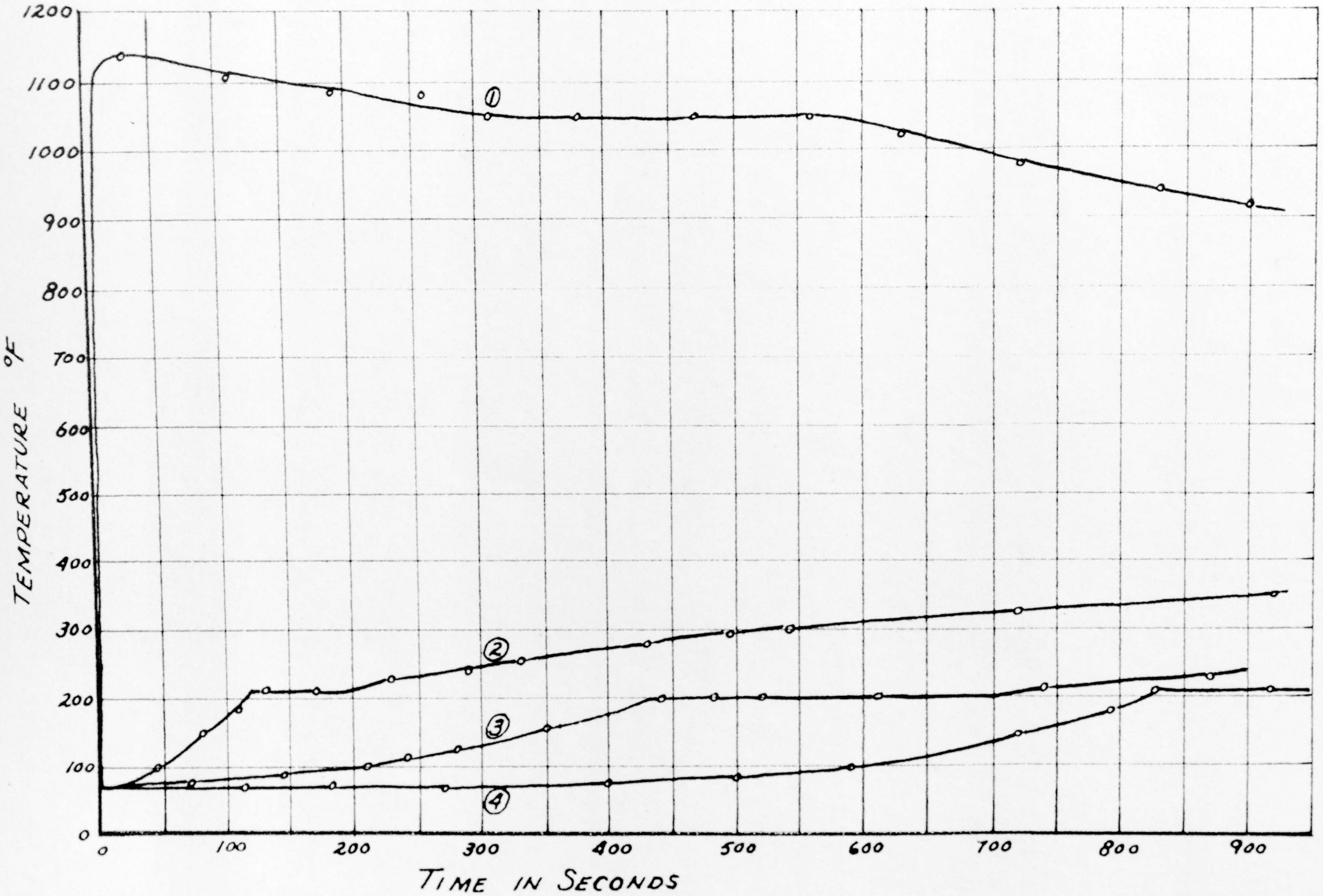


Table 10

Temperature - Time Data

Sand Sample No. 2

3 1/2% Southern Bentonite

3 1/2 % Western Bentonite

2.5% Moisture

Thermocouple readings in millivolts have been converted to ^{o}F.

Thermocouple 1		Thermocouple 2		Thermocouple 3		Thermocouple 4	
Time sec.	^{o}F	Time sec.	^{o}F	Time sec.	^{o}F	Time sec.	^{o}F
30	1160	35	100	105	97	75	75
60	1120	90	180	150	110	170	75
85	1165	100	200	200	125	280	80
120	1110	130	210	260	140	420	95
180	1110	195	210	330	165	560	120
220	1090	240	235	390	190	625	140
360	1045	370	260	470	190	740	170
450	1045	590	275	600	190	775	190
510	1045	660	300	675	200	860	190
530	1045	750	310	770	208		
575	1045	830	325	840	208		
645	1020	910	330	930	200		

Table 10 (continued)

Thermocouple 5		Thermocouple 6	
Time sec.	°F	Time sec.	°F
100	75	50	75
185	75	140	75
365	75	210	75
480	75	340	75
540	75	490	75
680	80	570	75
790	85	690	75
870	90	760	75
		850	80

Fig. (19) Temperature - Time Relationships

Sand Sample No. 2

3½ % Southern Bentonite
3½ % Western Bentonite

2.5 % Moisture

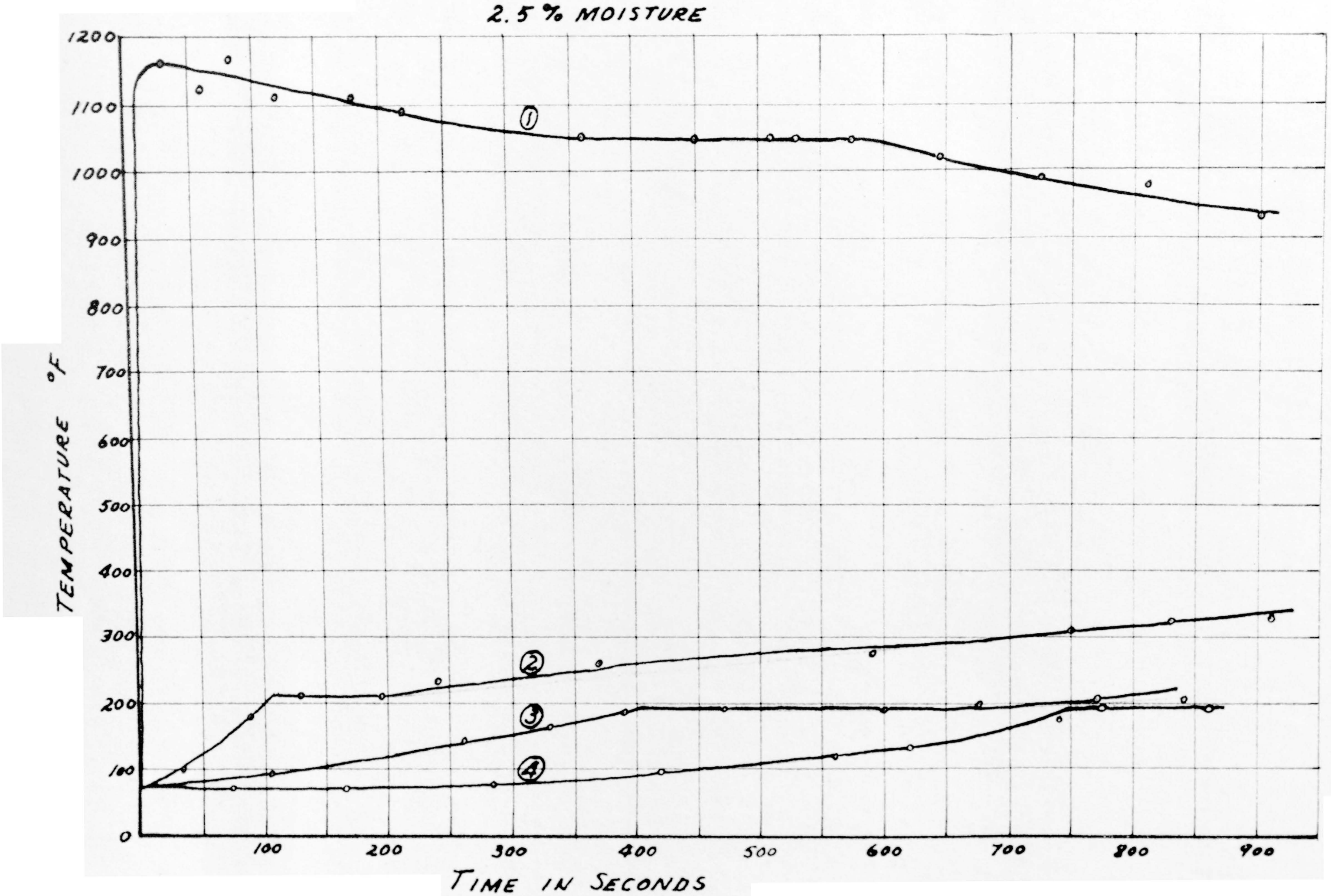


Table 11

Temperature - Time Data

Sand Sample No.2

3 1/2% Southern Bentonite

3 1/2% Western Bentonite

3.0% Moisture

Thermocouple readings in millivolts have been converted to °F.

Thermocouple 1 Time sec.	Thermocouple 1 °F	Thermocouple 2 Time sec.	Thermocouple 2 °F	Thermocouple 3 Time sec.	Thermocouple 3 °F	Thermocouple 4 Time sec.	Thermocouple 4 °F
20	1140	40	120	75	90	125	80
90	1125	70	160	150	110	185	85
140	1120	95	210	230	140	305	90
210	1100	160	210	330	180	500	120
270	1060	220	210	370	195	585	140
360	1045	265	210	460	200	690	175
430	1045	340	220	550	200	740	200
540	1045	440	240	640	200	810	200
670	1020	525	250	710	200		
780	975	620	265	815	200		
885	950	760	290				
		885	310				

FIG. 20 TEMPERATURE - TIME RELATIONSHIPS

SAND SAMPLE NO. 2

3½ % SOUTHERN BENTONITE
3½ % WESTERN BENTONITE

3.0 % MOISTURE

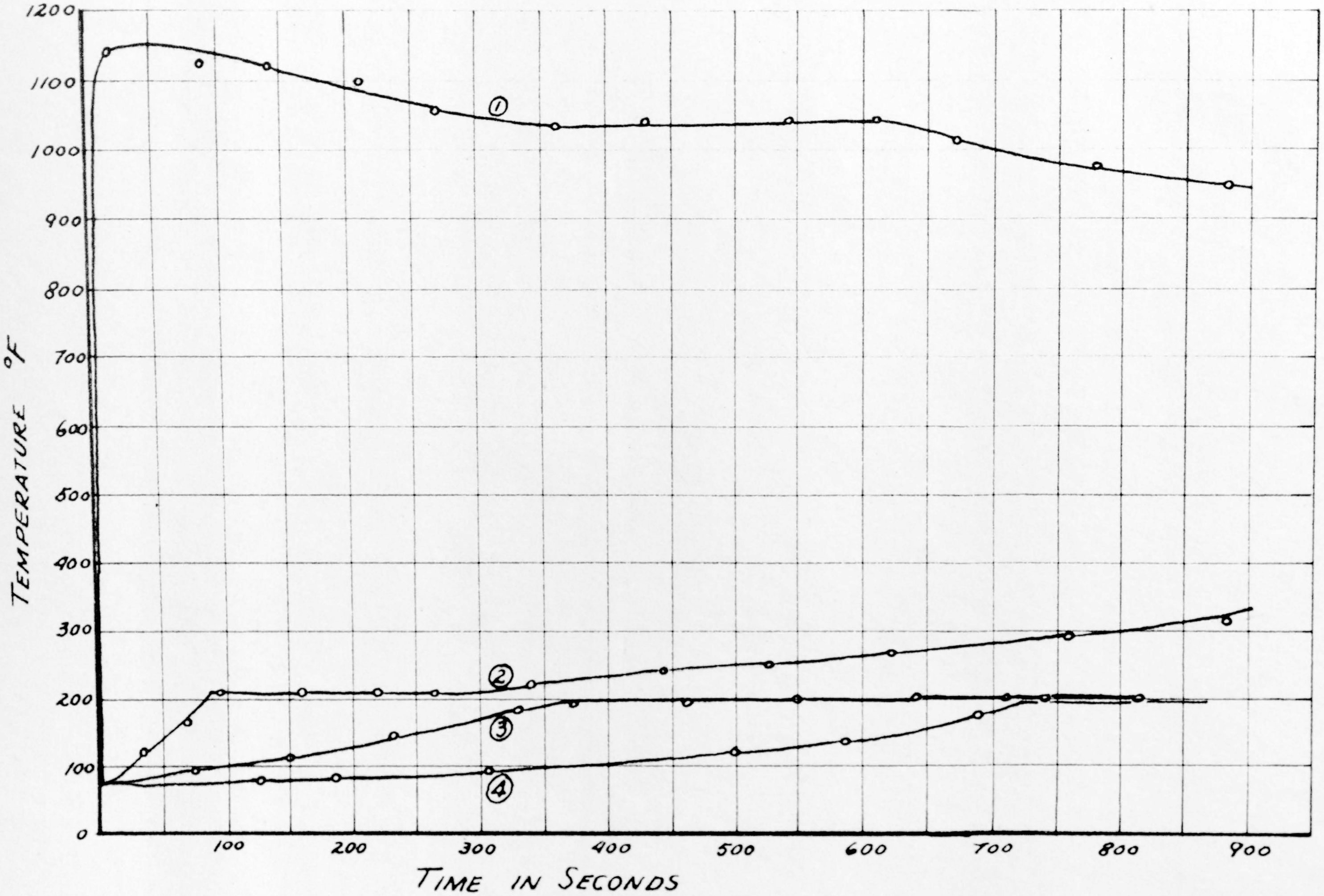


Table 12

Temperature - Time Data

Sand Sample No. 3

7% Western Bentonite

2.0% Moisture

Thermocouple readings in millivolts have been converted to °F.

Thermocouple 1		Thermocouple 2		Thermocouple 3		Thermocouple 4	
Time sec.	°F	Time sec.	°F	Time sec.	°F	Time sec.	°F
30	1130	50	100	60	80	95	75
70	1140	80	120	170	90	160	75
140	1105	120	160	280	110	220	75
230	1070	150	210	390	150	330	75
290	1050	210	210	485	200	510	80
370	1045	295	250	565	200	680	110
460	1045	380	260	670	200	780	160
580	1045	470	280	765	200	875	200
710	1005	595	310	860	220	925	200
840	975	725	320	910	225		
915	950	830	350				
		900	350				

FIG. (21) TEMPERATURE - TIME RELATIONSHIPS
SAND SAMPLE No. 3
7% WESTERN BENTONITE
2.0 % MOISTURE

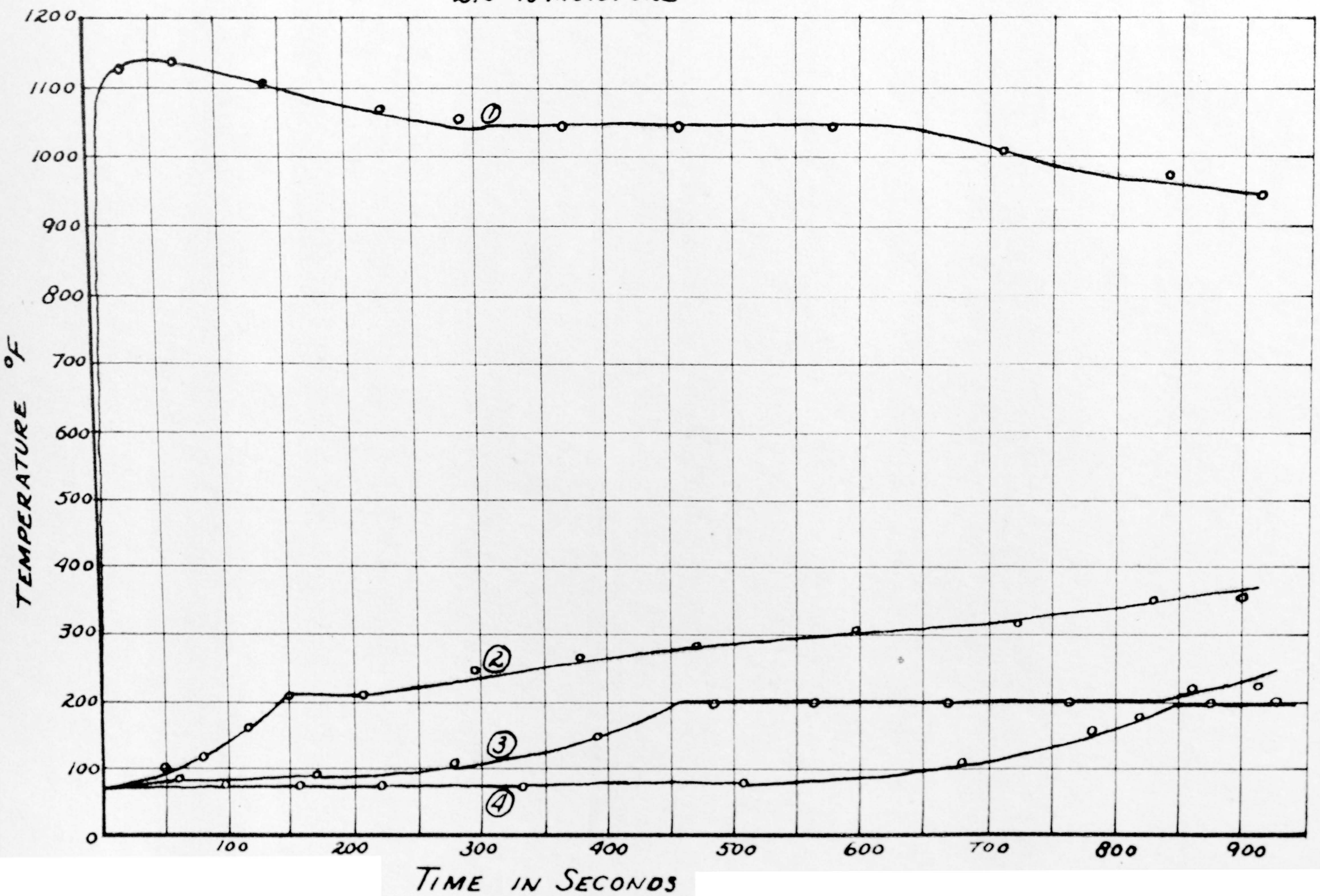


Table 13

Temperature - Time Data

Sand Sample No. 3

7% Western Bentonite

3.0% Moisture

Thermocouple readings in millivolts have been converted to °F.

Thermocouple 1		Thermocouple 2		Thermocouple 3		Thermocouple 4	
Time sec.	°F	Time sec.	°F	Time sec.	°F	Time sec.	°F
40	1140	45	100	60	80	90	75
80	1130	65	125	135	90	185	75
145	1140	95	160	245	110	280	75
240	1080	125	210	325	150	365	80
310	1045	165	210	400	170	515	90
380	1045	220	210	490	200	610	120
470	1045	260	215	575	200	640	110
590	1045	315	230	735	200	760	170
690	1010	390	230	875	200	810	200
820	970	480	250				
895	920	610	270				
		710	280				
		860	310				

FIG. 22 TEMPERATURE-TIME RELATIONSHIPS
SAND SAMPLE No. 3
7% WESTERN BENTONITE
3.0 % MOISTURE

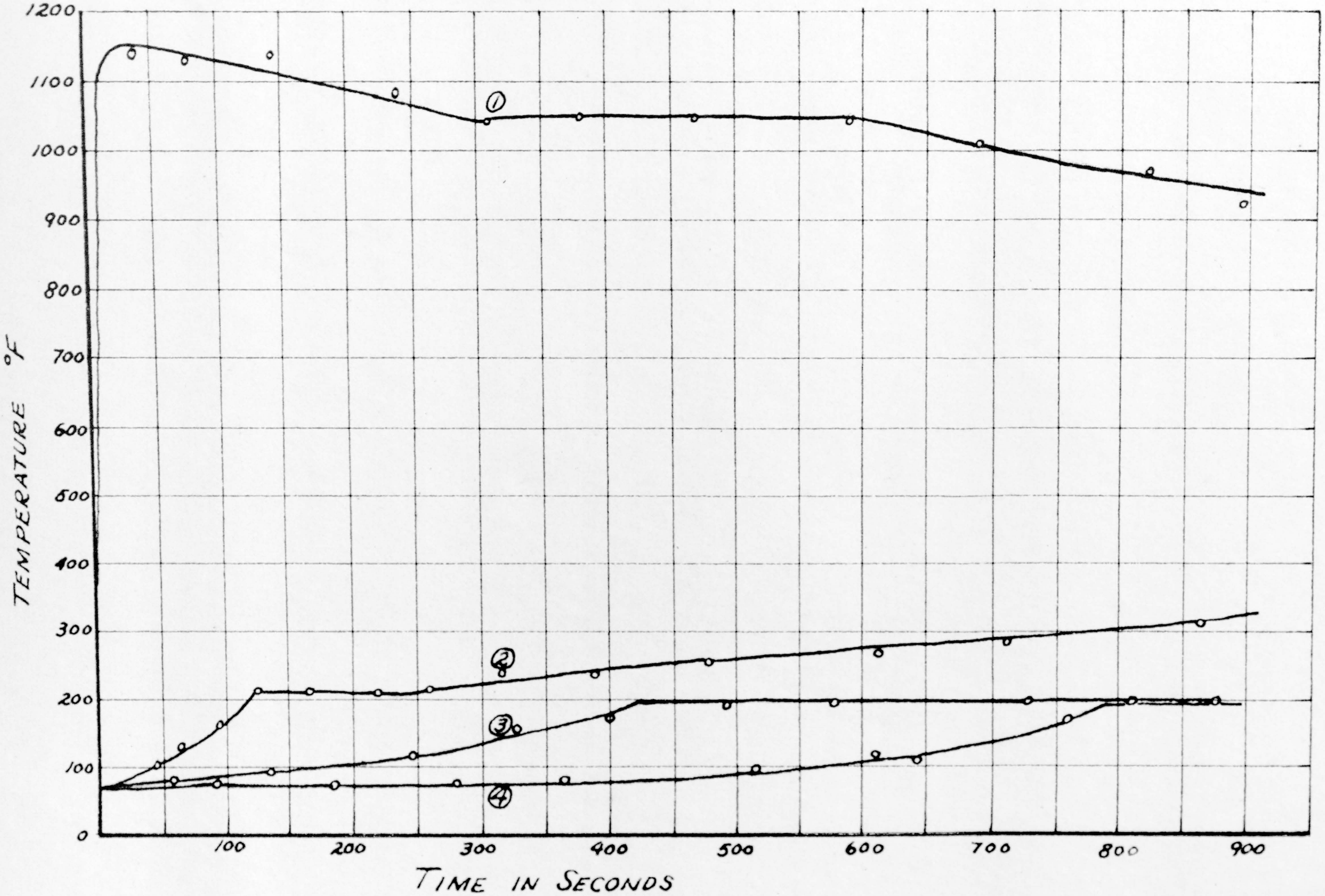


Table 14

Temperature - Time Data

Sand Sample No. 3

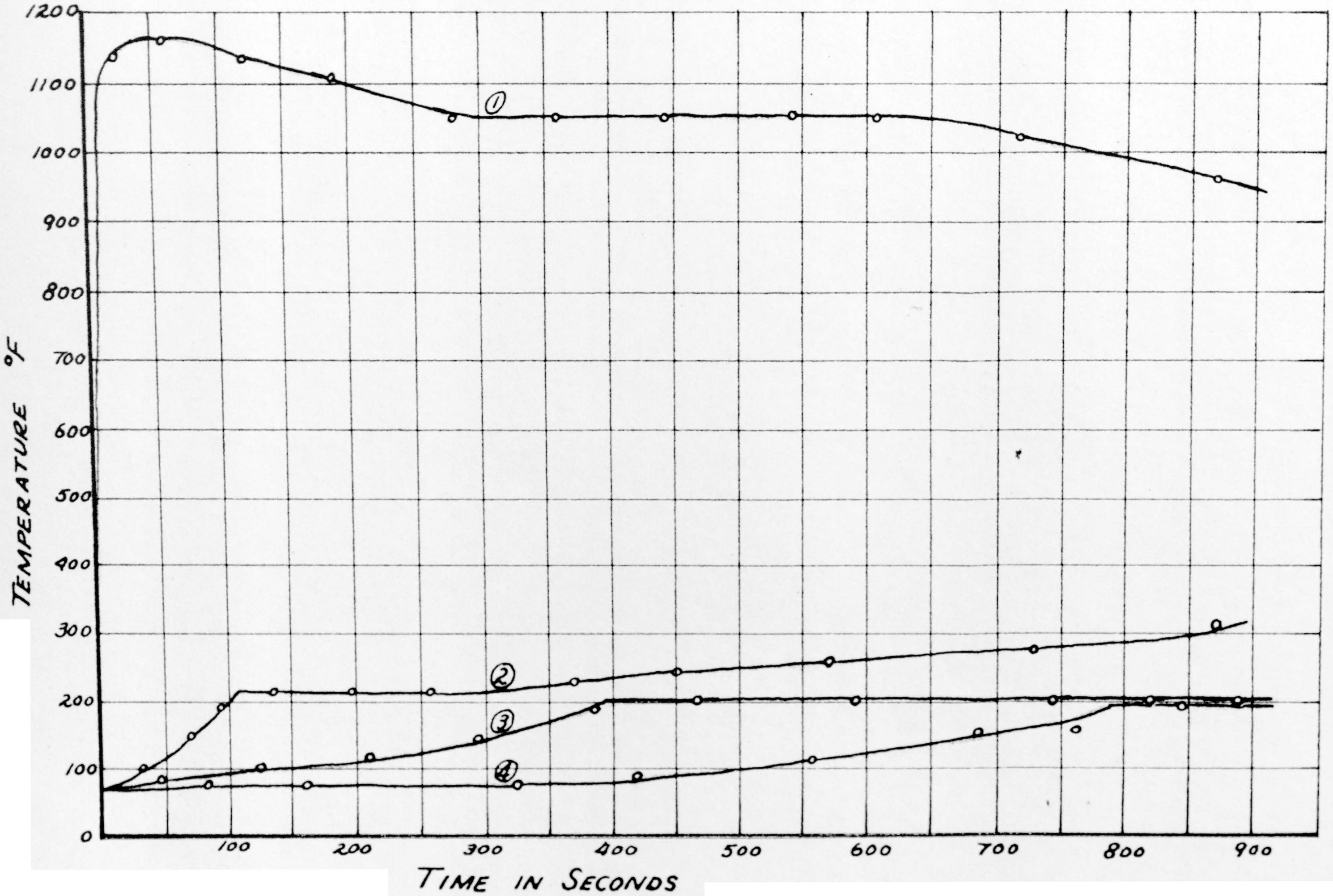
7% Western Bentonite

3.5% Moisture

Thermocouple readings in millivolts have been converted to °F.

Thermocouple 1 Time sec.	Thermocouple 1 °F	Thermocouple 2 Time sec.	Thermocouple 2 °F	Thermocouple 3 Time sec.	Thermocouple 3 °F	Thermocouple 4 Time sec.	Thermocouple 4 °F
20	1140	30	100	45	80	85	75
60	1160	70	150	125	100	160	75
120	1140	95	190	210	120	325	75
190	1105	135	210	295	140	420	90
280	1045	195	210	385	190	560	120
360	1045	260	210	470	200	685	150
440	1045	370	230	590	200	760	160
540	1045	450	240	740	200	845	200
610	1045	570	260	820	200		
715	1020	730	280	885	200		
870	960	875	310				

FIG. 23 TEMPERATURE-TIME RELATIONSHIPS
SAND SAMPLE NO. 3
7% WESTERN BENTONITE
3.5 % MOISTURE



CONCLUSIONS

Figures 24, 25, and 26 show the radial temperature distribution through the mold for the three sand samples at their most desireable moisture content. These three graphs have temperature as ordinate and distance from the metal-mold interface as abscissa. The instantaneous curves are shown for 100, 400, and 800 seconds in each graph. The values for these plots were taken from the previous curves of temperature versus time for each of the thermocouple positions.

Since only four positions were used, and the distances between these positions were fairly great, Figures 24, 25, and 26 show only the very general shape of the instantaneous temperature distribution curves, and should not be expected to yield exact values.

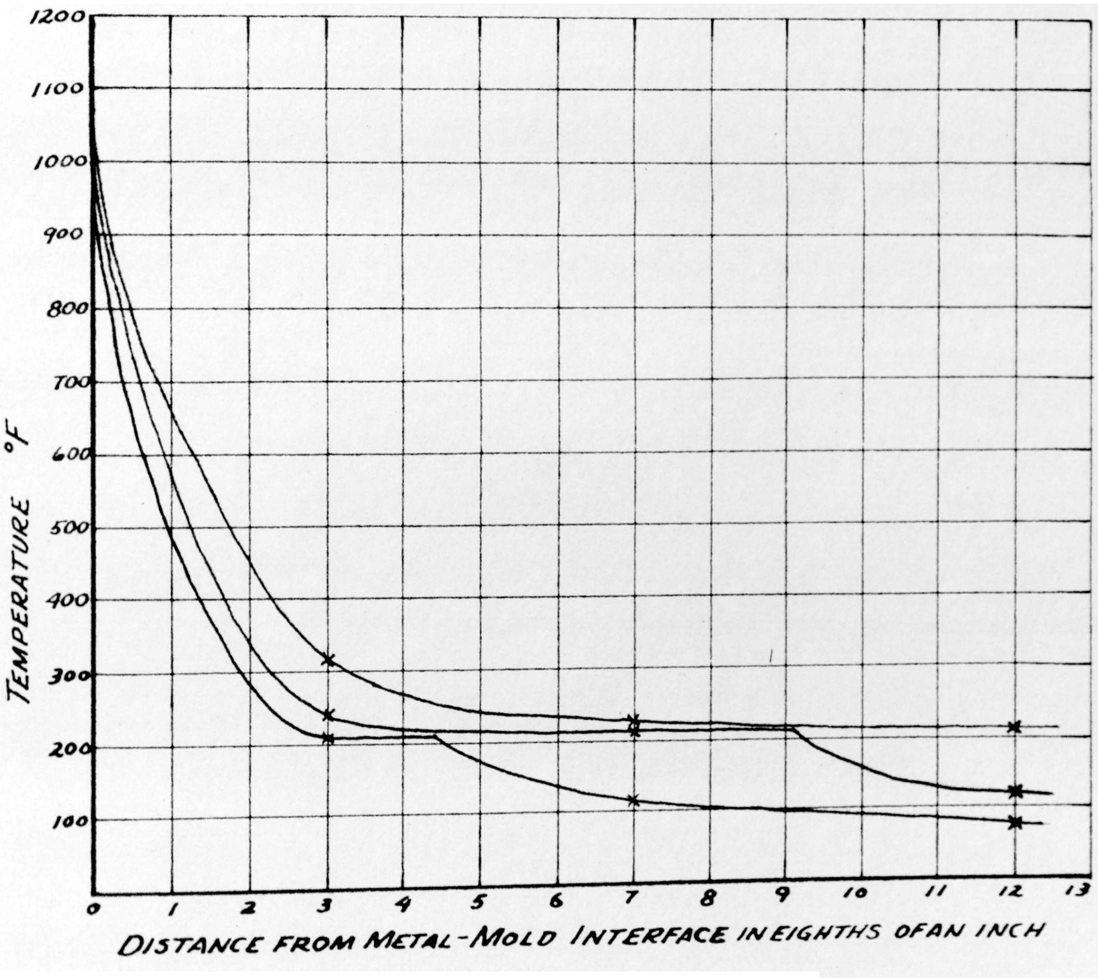


FIG. 24 RADIAL THERMAL GRADIENTS
AT 100, 400, AND 800 SECONDS

SAND SAMPLE NO. 1
7% SOUTHERN BENTONITE
2.75 % MOISTURE

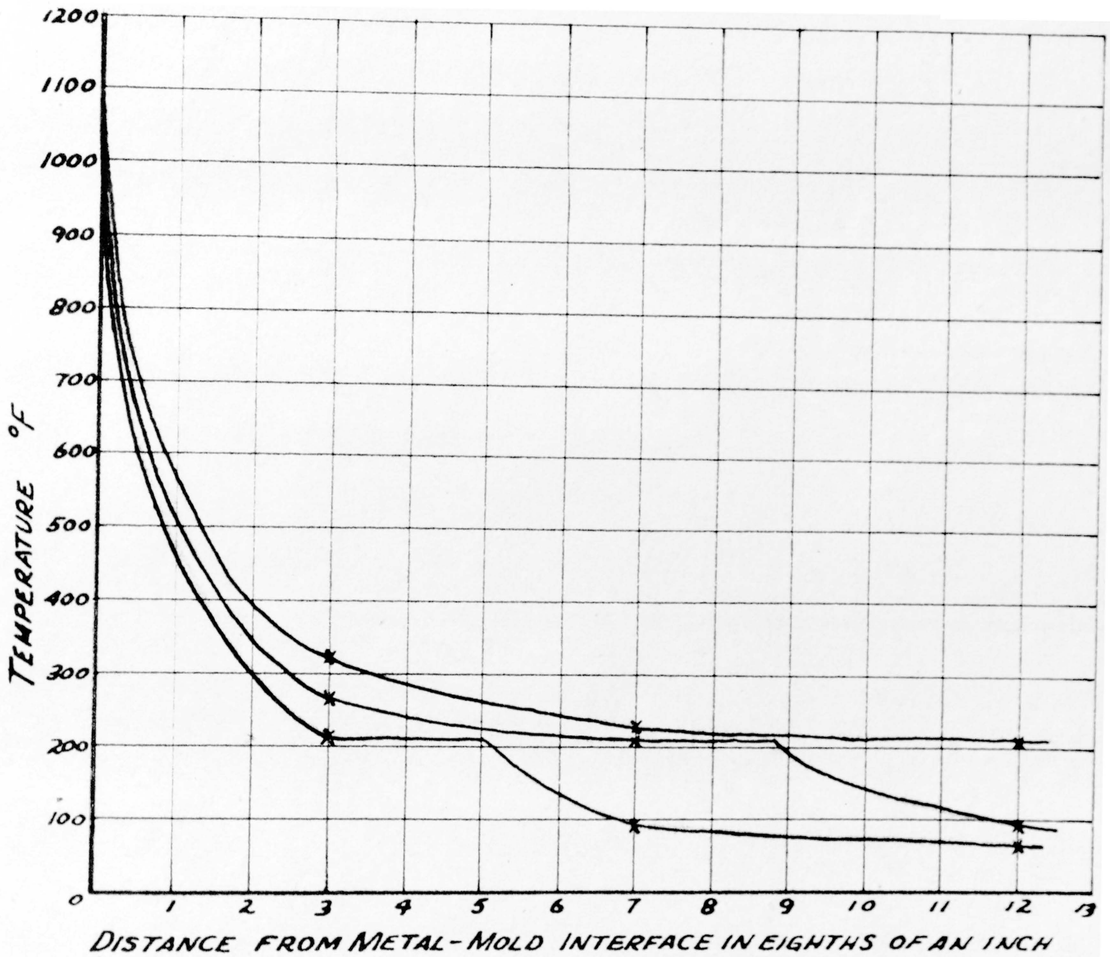


FIG. 25 RADIAL THERMAL GRADIENTS
AT 100, 400, AND 800 SECONDS

SAND SAMPLE NO. 2

3½ % SOUTHERN BENTONITE

3½ % WESTERN BENTONITE

2.5 % MOISTURE

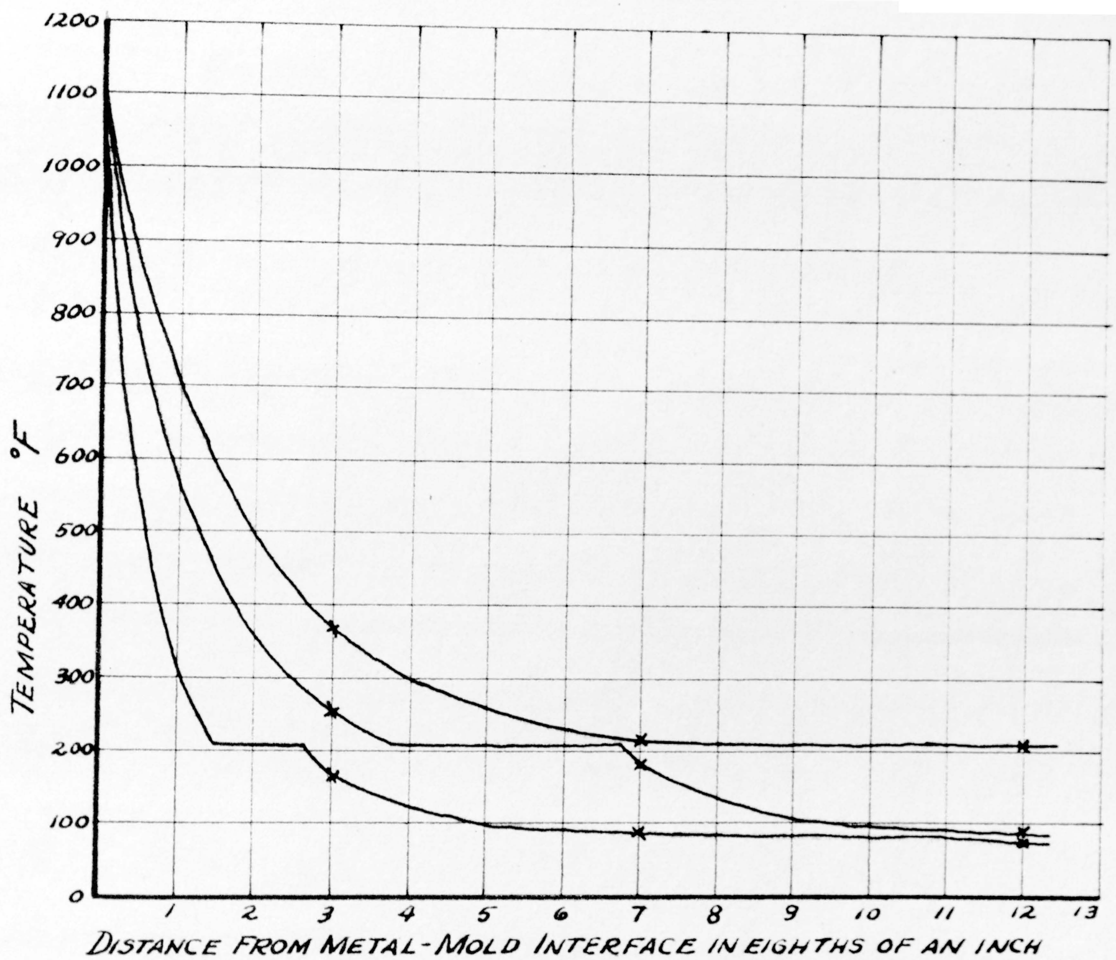


FIG. 26 RADIAL THERMAL GRADIENTS
AT 100, 400, AND 800 SECONDS

SAND SAMPLE NO. 3
7% WESTERN BENTONITE

3.0% MOISTURE

Since the curves for the No. 2 thermocouple position are all well-defined on the temperature-time graphs, they may easily be used to compare the effects of the nine different mixes on the rate of heat transfer through the sand.

Two values taken from these curves have been tabulated for each mixture in Table 15. They are: 1) the time necessary to reach the constant temperature portion of the curve, and 2) the time required for complete drying once this temperature has been reached. For each sample, the time necessary to reach the constant temperature portion decreases as the percent moisture increases. This relationship is shown in Figure 27. The plotted data appears to be quite inconsistant, therefore, no attempt is made to make a mathematical analysis. The inverse of the general trend of these curves shows the effect of the moisture on the apparent thermal conductivity of the moist sand; the mixes having the highest apparent conductivity take the least time to reach the boiling temperature of the moisture, and the mixes having the lowest apparent conductivity take the most time to reach the boiling temperature.

The same information for thermocouples 3 and 4 is shown on Tables 16 and 17, and the curves relating time to reach boiling temperature with percent moisture contained are shown in Figures 28 and 29.

Table 15

Time to Reach Boiling Temperature

and

Time to Completely Dry

Thermocouple Position No. 2

3/8 inch from Metal-Mold Interface

Sample No.	% Moisture	Time to reach B.P. (sec.)	Time to Dry (sec.)
1	2.0	85	95
1	2.75	75	135
1	3.5	60	190
2	1.5	120	60
2	2.5	110	80
2	3.0	85	195
3	2.0	150	60
3	3.0	125	115
3	3.5	110	165

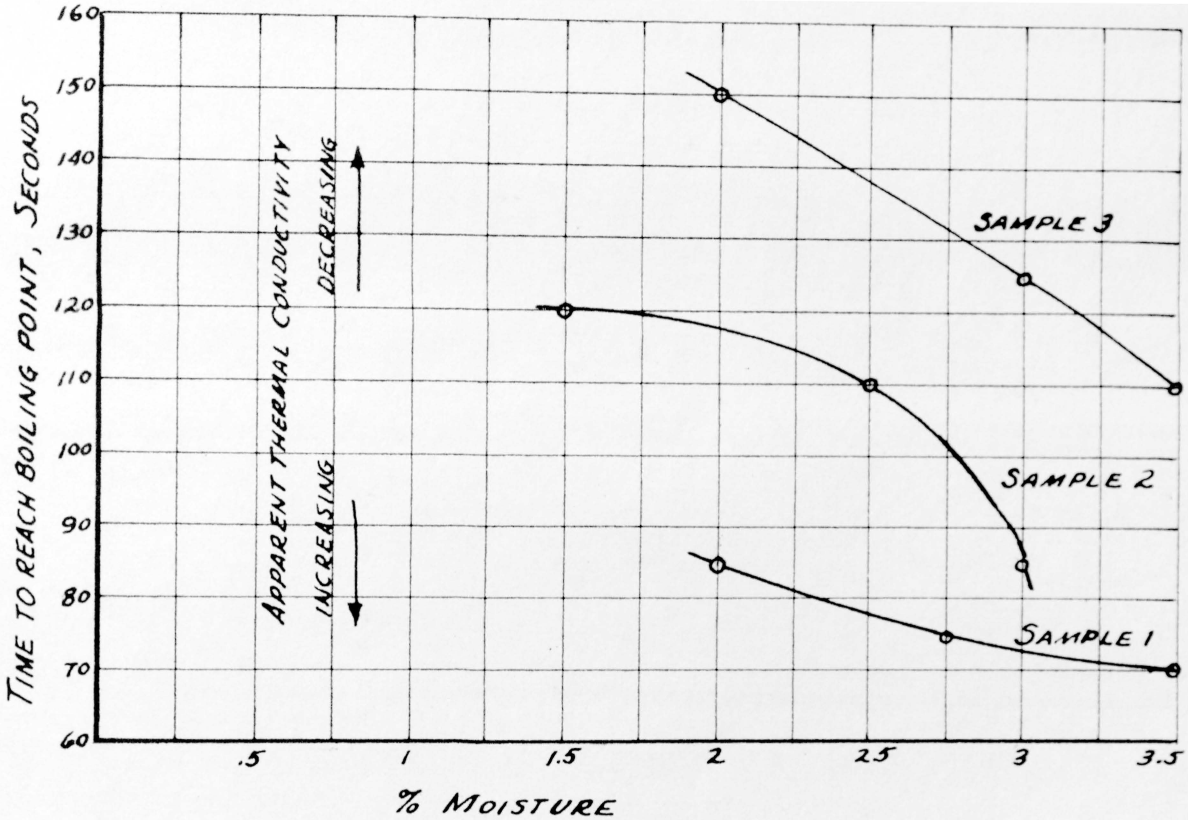


FIG. 27 RELATIONSHIP OF MOISTURE TO
TIME NECESSARY FOR SAND TO REACH BOILING POINT
POSITION NO. 2

Table 16

Time to Reach Boiling Temperature

and

Time to Completely Dry

Thermocouple Position No. 3

7/8 inch from Metal-Mold Interface

Sample No.	% Moisture	Time to Reach B.P. (sec.)	Time to Dry (sec.)
1	2.0	350	320
1	2.75	330	420
1	3.5	325	445
2	1.5	430	270
2	2.5	405	295
2	3.0	375	---
3	2.0	460	375
3	3.0	425	---
3	3.5	390	---

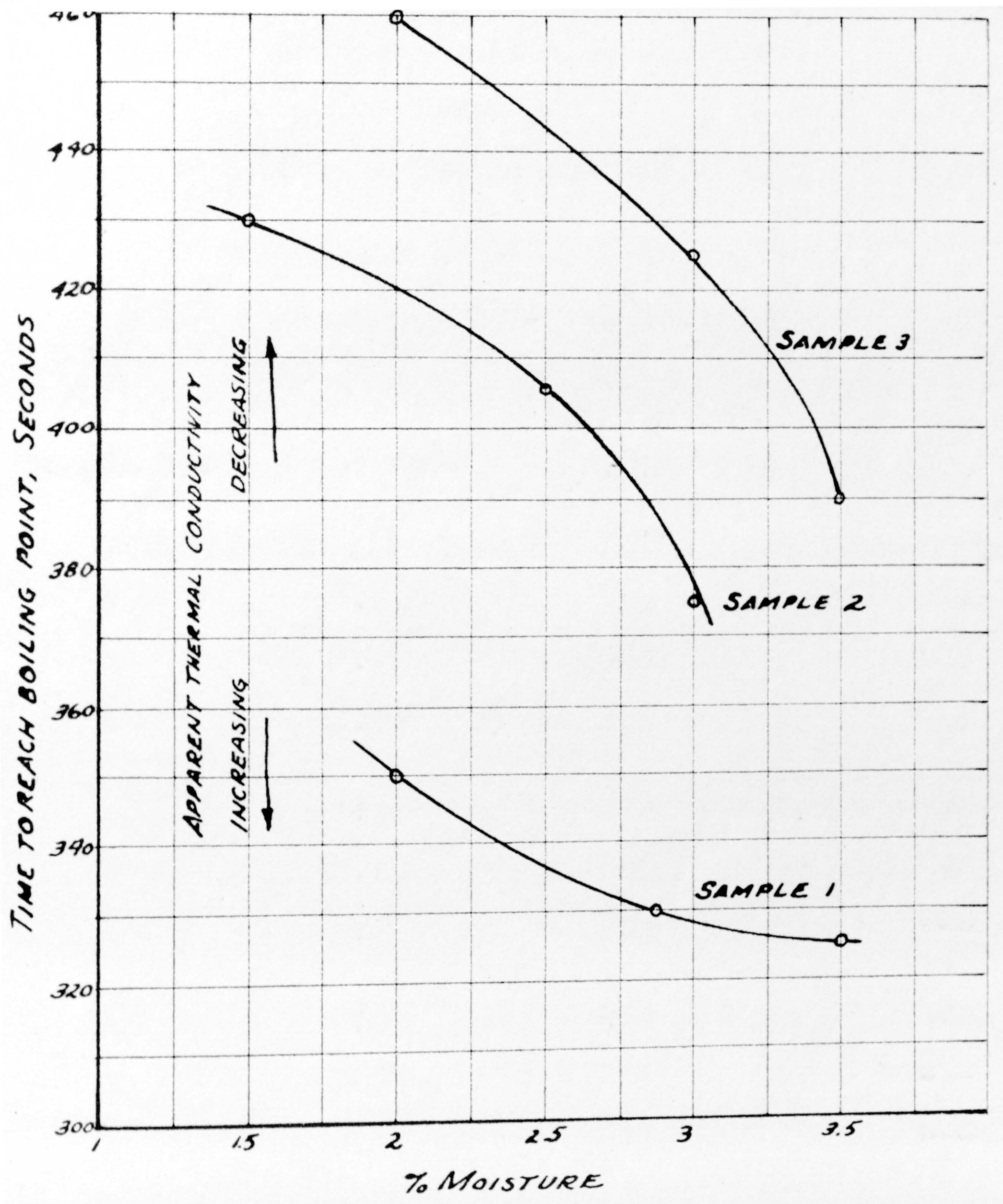


Fig. 28 Relationship of moisture to time necessary for sand to reach boiling point
Position No. 3

Table 17

Time to Reach Boiling Temperature

and

Time to Completely Dry

Thermocouple Position No. 4

1 1/2 inches from Metal-Mold Interface

Sample No.	% Moisture	Time to Reach B.P. (sec.)	Time to Dry (sec.)
1	2.0	770	---
1	2.75	670	---
1	3.5	635	---
2	1.5	830	---
2	2.5	750	---
2	3.0	720	---
3	2.0	850	---
3	3.0	785	---
3	3.5	780	---

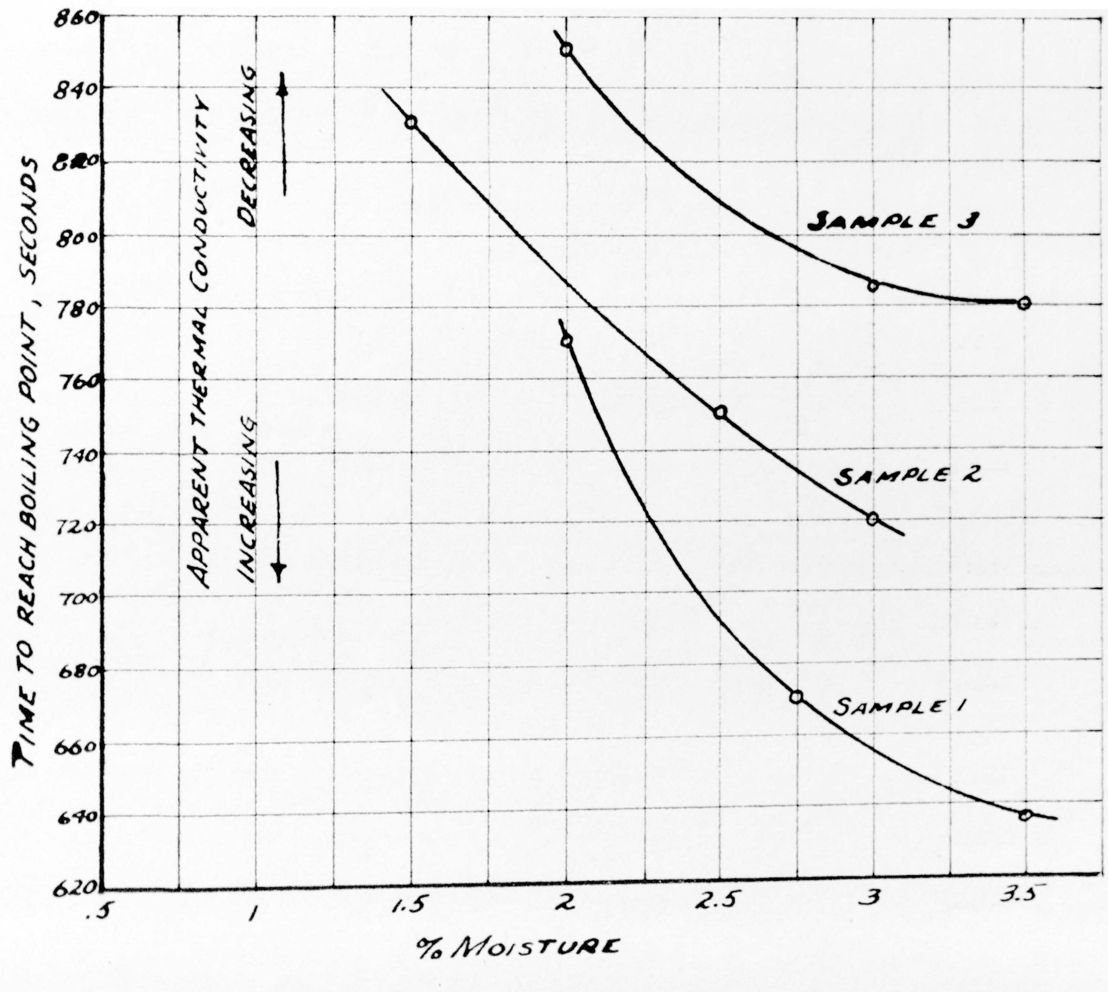


Fig. 29 Relationship of moisture to time necessary for sand to reach boiling point

Position No. 4

Comparing the apparent thermal conductivities of the sand samples from the standpoint of the type of binder used, it is found that the Southern Bentonite bonded sand has the highest rate of heat transfer and the Western Bentonite bonded sand the lowest, with the sand bonded with a combination of the two somewhere in between. Figure 30 was drawn to illustrate this. Values for the time necessary to reach the boiling point of the moisture shown in the figure are those at the most desireable moisture content as determined from the testing for green properties. The same order, however, would apparently hold true for any particular moisture content within the useable range.

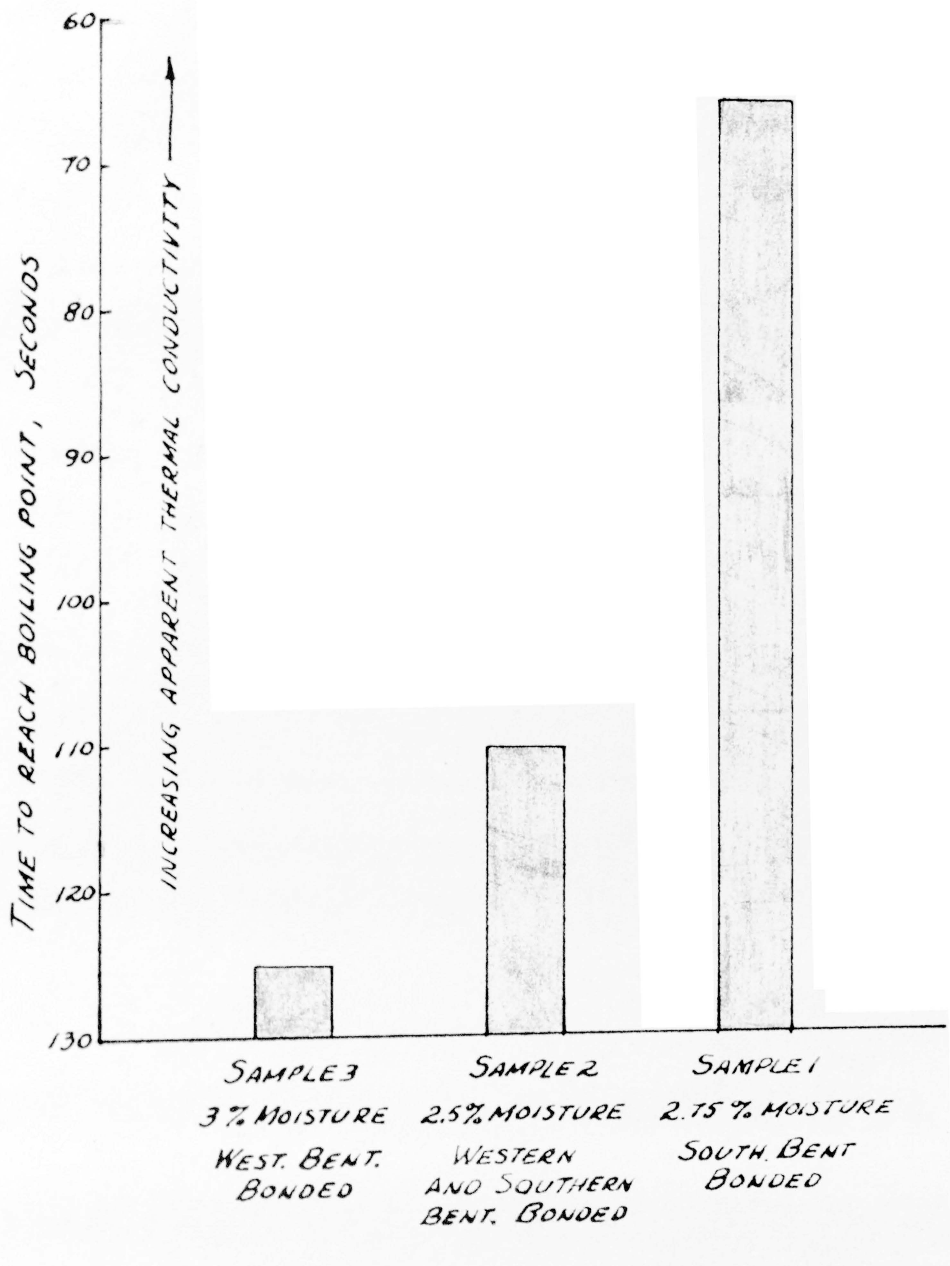


FIG. 30 COMPARISON OF APPARENT THERMAL CONDUCTIVITIES

SUMMARY

The purpose of the experimental work covered by this thesis was to investigate two of the factors affecting the rate of heat transfer in a green sand mold. The two factors investigated were 1) moisture content and 2) type of binder. Preliminary sand testing showed the useable moisture range for the three sand samples chosen for the heat transfer tests. All thermal testing was carried out with the moisture percents within this range.

Through the pouring of a cylindrical casting in a mold formed in a cylindrical flask, the temperature distribution curves and the curves of temperature with respect to time for chosen mold depths were found.

Several conclusions may be reached by close study of these curves:

1) The total casting solidification time is changed little by the two factors investigated.

2) There is an original chilling effect produced by the high conductivity of the moist sand before it reaches the boiling temperature of the contained moisture.

3) Apparent thermal conductivity of green sand increases as the moisture content increases.

4) Of the three samples tested, the Southern Bentonite bonded sand exhibits the greatest apparent conductivity, the Western Bentonite bonded gives the lowest conductivity, and the mixture of Southern and Western has a conductivity between the two.

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VITA

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